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FUNDAMENTAL EXPERIMENT ON THE ENGINEERING PROPERTIES OF CEMENT MIX MATERIALS FOR BASE COURSE

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This paper presents a comprehensive study to investigate compaction-strength mechanism as well as drying shrinkage characteristics on cement mix materials for base course with water content from low water content region which is suitable for roller-compaction to high water content region which is suitable for vibration-compaction. From the experiment results, dry density changes continuously with respect to water content of both regions and is maximum at the boundary. But at that boundary, compressive strength is different and incontinuous. In other words, compressive strength is not always governed by dry density and is found to be governed by cement-paste/void ratio. The drying shrinkage of these materials is linearly proportional to water content and cement content during mixing.
Keywords : *cement mix material, cement stabilized material, base course material*

1. INTRODUCTION

Cement stabilized materials are used as base course materials and constructed by roller compaction. The purpose of this kind of stabilization in Japan is to maintain the strength and the mechanical properties of the materials at a satisfactory level so that it will retain its original compacted state indefinitely under traffic and weather conditions by adding relatively small quantity of cement to granular materials. But in other countries, from the points of strengthening pavement against traffic load, active utilization of locally available aggregates through quality improvement and prevention against erosion, relatively high cement content materials like lean concrete are actively used. This material is also sometimes included in cement stabilized material[1]. Materials involved in this paper are of mixing of relatively large quantity of cement and to avoid confusion with cement stabilized materials used in Japan, we would like to name these materials cement mix materials.

Regarding this kind of materials in Japan, from the concept of crack susceptible to drying shrinkage, mix design is carried out with control over cement content. For example, according to the Cement Concrete Pavement Manual[2] and the Asphalt Pavement Manual[3], a rather small value of 10 kg/cm^2 and 30 kg/cm^2 respectively are used to design the compressive strength as the design strength of the cement stabilized base course materials. But in other countries especially in the case of concrete pavement, for instance in the United Kingdom, France and West Germany relatively high value of compressive strength of 70–140 kg/cm^2, 45–55 kg/cm^2 and 40 kg/cm^2 respectively are used as criteria[4]. Furthermore, recently France, West Germany and other countries apply actively considerably high strength lean concrete not only to strengthen pavement against traffic load but also from the point of prevention of base course from

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erosion[5]. These cement mix materials can be classified into two kinds. There are materials with water content that of conventional concrete for internal vibration compaction and materials with water content that of about the optimum moisture content of the granular materials for roller-compaction. Concerning the water content of the cement mix materials, we name the former high water content region and the latter low water content region in this paper. These materials as cement family base course materials are fundamentally the same family but the former with concrete engineering and the latter with soil engineering background. With these different backgrounds, engineers tend to handle these materials separately. Here, we carried out a comprehensive experiment on both regions of these cement mix materials to investigate the compaction-strength mechanism, as well as the drying shrinkage characteristics.

2. EXPERIMENTAL OUTLINE

(1) Types of experiment

Three types of experiment as below were carried out on cement mix materials.

Experiment-1 : Experiment on effect of compaction

Experiment-2 : Experiment on strength mechanism

Experiment-3 : Experiment on drying shrinkage

Table 1 Physical properties of aggregate.

type	place of origin	range of particle size (mm)	specific gravity	Los Angeles percentage of abrasion (%)	application
crushed stone dust	Shiroishi Hayama	0-2.5	2.60	-	experiment-1,2,3
sand	Shiroishi river	0-5	2.47	-	experiment-1,2,3
crushed stone No.7-sieve	Shiroishi Hayama	2.5-5	2.59	16	experiment-1,2
crushed stone No.6-sieve	Shiroishi Hayama	5-13	2.61	16	experiment-1,2

(2) Ingredients and mix proportions

Normal Portland cement was used in all experiments. River sand and crushed stone dust as fine aggregate and No. 6-sieve crushed stone and No. 7-sieve crushed stone as coarse aggregate were used. The physical properties of these aggregates are as shown in Table 1. In experiment-1 and experiment-2, No. 6-sieve crushed stone, No. 7-sieve crushed stone, river sand and crushed stone dust respectively were mixed with same aggregate proportion of 10 %, 35 %, 35 % and 20 % by weight respectively, but the properties of crushed stone dust are slightly different due to different production periods. And in experiment-3, due to restriction of test piece making, proportion of 64 % and 36 % of river sand and crushed stone dust were mixed.

The quantity of cement and water used in these cement mix materials are defined as follow :

Cement content=[cement weight/atmosphere dry aggregate weight]×100 (%)

Water content=[water weight/(atmosphere dry aggregate weight+cement weight)]×100 (%)

(3) Experiment-1

Test pieces were made by using cylinder mould of 10 cm internal diameter, 12.7 cm height and 1 000 cm^3 capacity. Compaction of materials were carried out by the following two methods : method-I for low water content region and method-II for high water content region.

I) Compaction by rammer

This method is based on JIS A 1210 with free fall of 2.5 kg rammer at 30 cm height. Materials were divided into 3 layers and compacted subsequently by 50 free falls for each layer.

II) Compaction by internal vibration

Internal vibrator (amplitude 0.8 mm, frequency 11 000 rpm) was inserted into the mould filled with materials and compacted adequately as that of the conventional concrete.

By these two methods, as will be mentioned later, almost same dry density can be obtained at the water content of the boundary of the concerned low water content region and the concerned high water content region experimentally.

Three test pieces were made from each batch and experiment results were shown by the average value. Test pieces were cured by wet mat for the first day and subsequently wrapped by thin polyfilm to prevent water loss for next 27 days at 20°C temperature. Loading test was carried out immediately after curing.

(4) Experiment-2

Test pieces were made by method-I of experiment-1 on materials of low water content region. Materials were divided into three layers and compacted each layer by 25, 50 and 75 free falls. Number of test pieces from each batch were same as experiment-1 and 7 days of wet curing were done, and subsequently loading test was carried out.

(5) Experiment-3

Test pieces were made by using 10 cm×10 cm×40 cm mould. Compaction of materials were carried out by rammer for low water content region and by internal vibration for high water content region. In the case of compaction by rammer, number of free fall per unit volume is according to JIS A 1210. Test pieces were kept at constant condition of 20°C and 60 % humidity.

Contact gauge was used in measuring of drying shrinkage. 24 hr after test piece making, measuring points with 10 cm interval were glued on the side of the test piece. Taking glue hardening time as starting time and measuring of length and weight change were carried out till 26 th week.

3. COMPACTION CHARACTERISTICS

(1) Dry density and water content

By using these two compaction methods, the interrelationships between water content, dry density and compressive strength of cement mix materials for water content from low to high water content region were investigated. Relationship between water content during test piece making and dry density of the experiment results for 6 %, 10 % and 14 % cement content are shown in Fig. 1. For 6 % to 10 % water content region, as above mentioned, test pieces were made by rammer and for 10 % to 13 % water content region, test pieces were made by internal vibration.

Dry density of the low water content region increases with increase of water content during compaction but in the case of high cement content, after a certain dry density was attained, dry density remains almost unchanged with respect to increase of water content. On the other hand, dry density of the high water content region decreases with increase of water content. Subsequently, in the experiment range of water content, at the boundary of low water content region and high water content region or in other words, at the boundary of different compaction methods, the respective dry densities were maximum and about same value for each cement content.

(2) Compressive strength and water content

Fig. 2 shows the relationship between water content during test piece making and compressive strength of experiment results for 6 %, 10 % and 14 % cement content. Compressive strength of the high water content region decreases uniformly with increase of water content as of the relationship between dry density and water content. But in the case of low water content region, inverted U-curves are formed where there are optimum water content in which the compressive strength is maximum and the behavior is very different from the relationship between dry density and water content. At the boundary of low water content region and high water content region, the compressive strength is incontinuous where the values are different for each method.

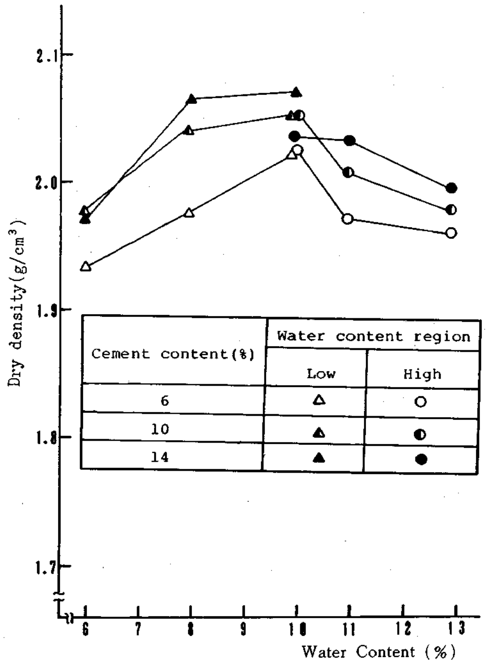

Fig. 1 Relationship between water content and dry density.

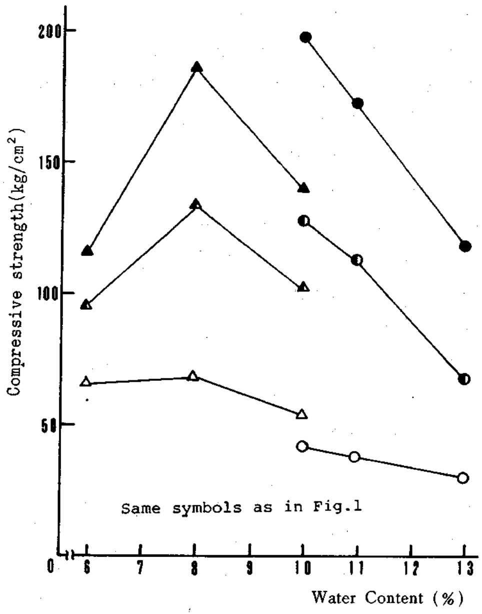

Fig. 2 Relationship between water content and compressive strength.

4. STRENGTH MECHANISM

(1) Experiment-1

Fig. 3 is the graph of relationship between strength and water/cement ratio obtained from data of experiment-1. By keeping water content constant and changing cement content in his research, Williams[6] relates the holding of water/cement ratio rule to the case of low cement content cement stabilized materials. In this experiment, relationship between strength and water/cement ratio of test piece of high water content region made by internal vibration also follows the water/cement ratio rule just as the conventional concrete and for each cement group, it shows nearly linear relationship.

On the other hand, regarding low water content region, relationship between compressive strength and water/cement ratio of test piece made by rammer especially in the case of high cement content of 10 % and 14 % forms inverted U-curve where there is a optimum water/cement ratio in which the strength is maximum. The relationship is similar to the relationship between compressive strength and water content as mentioned in Section 3. It is comprehensive that the straight lines of high water content region as above-mentioned forms the envelope line of compressive strength-water/cement ratio curves of low water content region. From this comprehensible study, it is reasonable to say that the region wetter than optimum water content of low water content region is the region where the compressive strength is fundamentally governed by water/cement ratio as in the case of high water content region.

(2) Experiment-2

From experiment-1, regarding compaction curves of low water content region, for region drier than optimum water content, with increase of water content or water/cement ratio, dry density as well as compressive strength also increases. The behaviour of compaction and strength mechanism of cement mix materials in this region may be explained from the point of compaction mechanism of granular materials or cement stabilized materials. The role of cement paste in this region is to increase the internal friction by lubrication function of the water during compaction and to develop strength through hydration reaction after cement hardening. To investigate the strength mechanism of low water content region especially the

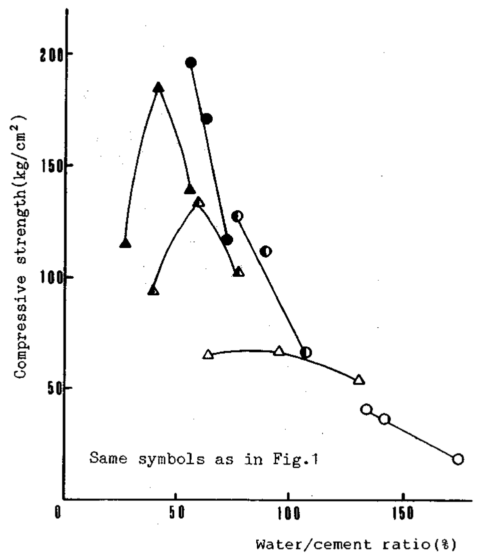

Fig. 3 Relationship between water/cement ratio and compressive strength.

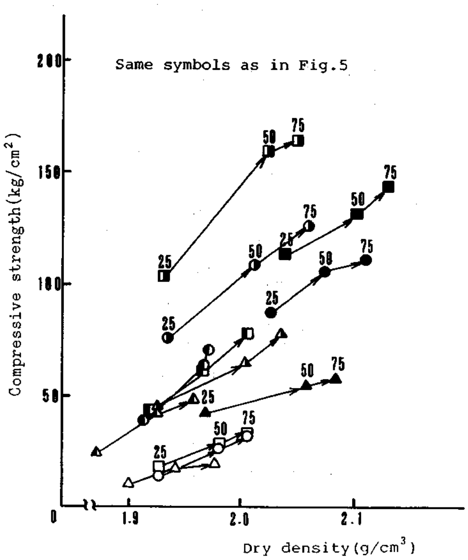

Fig. 4 Relationship between dry density and compressive strength.

region that is drier than optimum water content, experiment-2 with variation of 25, 50, 75 number of free falls for each layer were carried out. From this experiment results, relationship between dry density and compressive strength is as shown in Fig. 4. Based on the concept of the correlation between strength and dry density of cement mix materials of low water content region which is generally constructed by roller-compaction, quality control will be carried out by density in many cases. But it is very clear from Fig. 4 that the relationship is scatter and the strength of cement mix materials of low water content region does not only depend on dry density.

In the case of roller-compacted concrete for dam and pavement, the strength is generally expressed by water/cement ratio and air void as parameters[7], and by cement/void ratio[8]. In this study, the parameters were investigated and it is found that in the case of cement mix materials, correlation between compressive strength and cement-paste/void ratio as defined below is very high.

cement-paste/void ratio= (volume occupied by cement and water) / (volume occupied by air void and water)

cement/void ratio= (volume occupied by cement) / (volume occupied by air void and water)

Fig. 5 is the graph of experiment-2 results. Result changed by variation of number of free falls of rammer are shown by arrows. From these results, relationship between compressive strength and cement/void ratio can be classified by water content during compaction and the influence of water content is very great. Here, instead of cement/void ratio, cement-paste/void ratio where water/void ratio is taken into consideration in addition the cement/void ratio is used. The experiment results are as shown in Fig. 6. From this, it is clear that different experiment data of region drier or wetter than optimum water content can be classified and for each region, the strength can be expressed in terms of cement paste/void ratio.

2. DRYING SHRINKAGE

Fig. 7 is the graph showing drying shrinkage and weight change of test pieces (water content 16 %) made by vibration and test pieces (water content 10 %) made by rammer with respect to time elapsed. For each method, 6 % and 14 % of two kinds of cement content were made and results are shown by the average value of 3 test pieces.

Weight change seems to be terminated after about 3 weeks but it takes about 10 weeks for drying

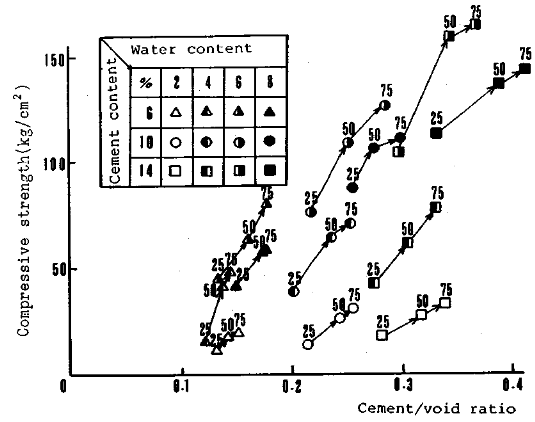

Fig. 5 Relationship between cement/void ratio and compressive strength.

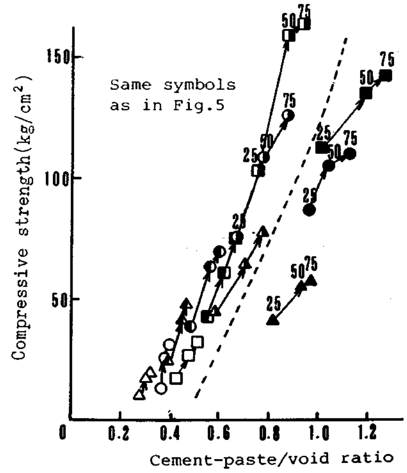

Fig. 6 Relationship between cement-paste/void and compressive strength.

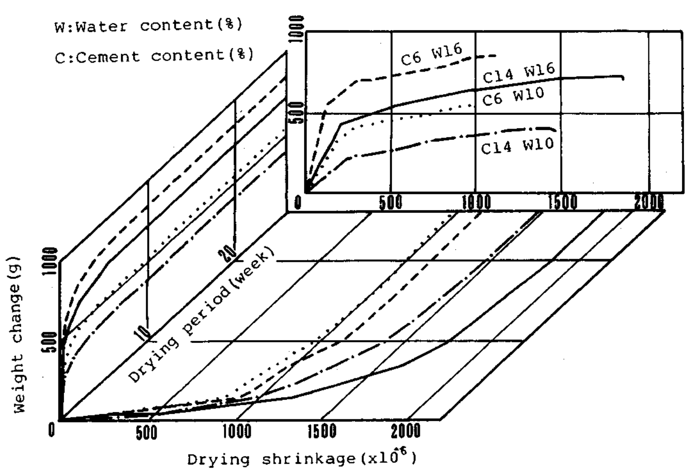

Fig. 7 Relationship between drying shrinkage and weight change.

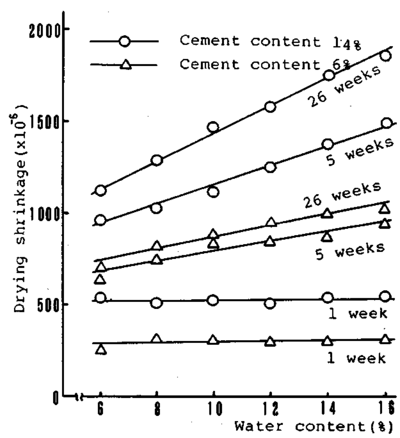

Fig. 8 Relationship between water content and drying shrinkage.

shrinkage to terminate. Therefore, the relationship between weight change and drying shrinkage is not linear. For a constant weight change or in other words, water loss through evaporation, drying shrinkage of test pieces with 14 % of cement content is bigger than test pieces with 6 % of cement content and similarly drying shrinkage of test pieces with 10 % of water content is bigger than test pieces with 16 % of water content.

Fig. 8 is the graph of relationship between water content during mixing and drying shrinkage for each time elapsed with test piece cement content of 6 % and 14 %. Test piece water content of 6 %, 8 % and 10 % were made by rammer and test piece water content of 12 %, 14 % and 16 % were made by internal vibration.

From the results, drying shrinkage of cement mix materials is independent of test piece making method and linearly proportional to water content of test piece. And the slopes of lines of linear relation are steeper for higher cement content and also steeper for longer time elapsed.

6. CONCLUSION

The fundamental properties of the experiment results regarding compaction mechanism, strength mechanism as well as drying shrinkage of cement mix materials for base course have been discussed. These will be summarized as follows :

(1) Test pieces of low water content region which is suitable for roller-compaction and test pieces of high water content region which is suitable for vibration-compaction were made by rammer and internal vibration respectively. From the result of investigation of both of the compaction characteristics, dry density at the boundary of low water content region and high water content region was maximum, and the values were same for each method. But regarding the compressive strength, independent behaviour was found for low water content and high water content and the values at the boundary point were incontinuous.

(2) Compressive strength of the high water content region was found to be governed by water/cement ratio as conventional concrete. The compressive strength-water/cement ratio curve of the high water content region formed the envelope curve of curves of compressive strength-water/cement ratio of low water content. From this, it is reasonable to say for region wetter than the optimum water content of the low water content region, the compressive strength is also governed by water/cement ratio.

(3) Regarding the region drier than the optimum water content of low water content region, the compressive strength is greatly influenced by dry density, water content and cement content. High correlationship between compressive strength and cement-paste/void ratio was accepted.

(4) The drying shrinkage of cement mix materials is not related to test piece making method and is directly related to water content and cement content during mixing.

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