

[DESCRIPTION]

[Title of Invention]

EVALUATION DEVICE FOR EVALUATING PROPERTIES OF CONCRETE, AND
5 METHOD FOR EVALUATING PROPERTIES OF CONCRETE

[Technical Field]

[0001]

The present invention relates to an evaluation device for evaluating properties
10 of concrete, and a method for evaluating properties of concrete using the device.

[Background Art]

[0002]

Generally, concrete used in large-scale (large-sized, large-section) structures
15 (mass concrete) is prone to thermal strain caused by temperature changes in individual
parts of the structure. Thermal strain can be a factor that leads to thermal cracking in
mass concrete. Therefore, it is important to evaluate the risk of thermal cracking in mass
concrete.

[0003]

20 There are known devices called thermal stress testing machines (TSTMs) that
are used to experimentally evaluate thermal cracking properties in concrete. These
devices are uniaxially confined testing devices that allow arbitrary control of
temperature conditions and confinement conditions of concrete in an adiabatic state.
With TSTM devices, it is possible to perform both a confined test for evaluating the
25 properties of concrete under confinement while changing the temperature conditions,

and an unconfined test for evaluating the properties of concrete in an unconfined state while changing the temperature conditions.

[0004]

However, TSTM devices are large in scale due to, for example, the need for control of water flow for temperature management, and more specifically, control of water temperature and volume. In addition, the mechanisms for the above control and the like require maintenance to keep a high level of accuracy in the test results. For these reasons, TSTM devices are usually installed in test rooms with ample space, making it difficult to evaluate concrete that is actually used in the field.

[0005]

PTL 1 (Japanese Laid-Open Patent Publication No. 2019-078614) discloses a testing device that is easy to handle and capable of performing tests on the mechanical properties of concrete in a reproduced adiabatic state.

[Citation List]

[Patent Literature]

[0006]

PTL 1: Japanese Laid-Open Patent Publication No. 2019-078614

[Summary of Invention]

[Technical Problem]

[0007]

In evaluating the risk of thermal cracking in mass concrete, a commonly employed method is to acquire various physical properties of concrete and then calculate thermal stress by numerical analysis using the acquired data as input. The

numerical analysis requires a variety of physical property values of concrete, and typical examples of the physical properties include compressive strength, tensile strength, Young's modulus, temperature rise, autogenous shrinkage strain, thermal expansion coefficient, and the like.

5 **[0008]**

The testing device disclosed in PTL 1 can be used to obtain adiabatic temperature characteristics and mechanical properties such as compressive strength, but this is insufficient as data necessary to evaluate the risk of thermal cracking.

[0009]

10 In view of the above-described issue, an object of the present invention is to provide an evaluation device that can acquire a variety of physical property values of concrete necessary for evaluating the risk of thermal cracking, even when using concrete made of the same material as concrete used in the field. Furthermore, another object of the present invention is to provide a method for evaluating properties of
15 concrete using the evaluation device.

[Solution to Problem]

[0010]

An evaluation device according to the present invention is an evaluation device
20 for evaluating properties of concrete to be measured, the evaluation device including:
a strength test unit including a plurality of first cylindrical molds, each
configured to receive cast concrete;
an unconfined test unit including a first rectangular frame having a bottom and
configured to receive cast concrete;
25 a confined test unit including a second rectangular frame having a bottom and

configured to receive cast concrete, both ends of the second rectangular frame in a longitudinal direction being restrained by a confining steel member having a thermal expansion coefficient of less than $1 \times 10^{-6}/^{\circ}\text{C}$;

a heat-insulated storage container covering the strength test unit, the
5 unconfined test unit, and the confined test unit; and
a thermometer configured to measure a temperature change inside the storage container,

wherein the unconfined test unit has a first strain sensor disposed within the first rectangular frame, and

10 the confined test unit has a second strain sensor disposed on the confining steel member.

[0011]

The evaluation device is used in a state where a plurality of test specimens, each obtained by casting concrete to be evaluated into the first cylindrical molds, the
15 first rectangular frame, and the second rectangular frame, are placed in the heat-insulated storage container. The concrete to be evaluated here may be concrete that is actually poured in the field, or concrete supplied from a concrete plant and made of the same material as concrete to be poured in the field.

[0012]

20 A plurality of test specimens (strength test specimens) obtained by casting the concrete into the first cylindrical molds are placed in the storage container.

[0013]

For example, each time a predetermined material-age timing is reached, a target material-age strength test specimen belonging to the plurality of strength test
25 specimens is removed from the storage container, and a Young's modulus measurement

test is executed on the target material-age strength test specimen, thereby calculating a pattern of change over time in a Young's modulus of the concrete. The Young's modulus measurement test is performed by a method complying with JIS A 1149:2017 “Method of test for static modulus of elasticity of concrete”, for example.

5 **[0014]**

As a more specific example, after each lapse of material ages of 1, 3, 7, 14, and 28 days, a strength test specimen is removed from the storage container and subjected to the above test. At this time, a heat-insulating filler may be placed inside the storage container to fill a gap created by removal of the strength test specimen (a region
10 previously occupied by the strength test specimen). Typically, the heat-insulating filler can be foamed beads, foamed polystyrene, rock wool, glass wool, foamed polyurethane, or the like.

[0015]

By executing a compressive strength test on the target material-age strength
15 test specimen, a pattern of change over time in a compressive strength of the concrete can be calculated. The compressive strength test is performed by a method complying with JIS A 1108:2018 “Method of test for compressive strength of concrete”, for example. The compressive strength test may be performed in parallel with the Young's modulus measurement test described above. The compressive strength of the concrete
20 and the Young's modulus of the concrete at each material age obtained in this way may be used to derive a correlation between the two.

[0016]

By executing a splitting tensile strength test on the target material-age strength test specimen, a pattern of change over time in a splitting tensile strength of the concrete
25 can be calculated. The splitting tensile strength test is performed by a method

complying with JIS A 1113:2018 “Method of test for splitting tensile strength of concrete”, for example.

[0017]

When executing the compressive strength test and the splitting tensile strength
5 test on strength test specimens of the same material age, it is preferable to prepare the
strength test specimens in a number equal to or greater than twice the number of types
of material ages in a strength test of the concrete. For example, after each lapse of
material ages of 1, 3, 7, 14, and 28 days, two or more strength test specimens are
removed from the storage container and subjected to the compressive strength test and
10 the splitting tensile strength test. The compressive strength test and the Young's
modulus measurement test may be performed in parallel on the same strength test
specimen.

[0018]

It is acceptable to perform the same test on a plurality of strength test
15 specimens of the same material age and to use a value (for example, an average value)
obtained by calculation based on the resultant measurements as a measurement value
obtained from the test result.

[0019]

As described above, each time a material-age timing is reached, a strength test
20 specimen is removed from the storage container. On the other hand, an unconfined test
specimen and a confined test specimen remain placed in the storage container for a long
period of time (for example, 25 days or more). From this perspective, for easy removal
of the strength test specimens, it is preferable that the storage container is made of a
heat-insulating material and has a removable lid portion, and that the strength test
25 specimens are placed above the unconfined test specimen and the confined test

specimen (on a side closer to the lid portion) in the storage container.

[0020]

As a more detailed example,

the storage container may have a bottom portion positioned opposite the lid

5 portion and side portions that cover the bottom portion from four directions;

the unconfined test unit and the confined test unit may be arranged in a

direction along the bottom portion; and

a plurality of first cylindrical molds included in the strength test unit may be

arranged in a direction along the bottom portion in a state of being placed directly over a

10 first rectangular frame included in the unconfined test unit and a second rectangular frame included in the confined test unit.

[0021]

A test specimen (unconfined test specimen) obtained by casting the concrete into the first rectangular frame is implemented with a first strain sensor embedded

15 inside. The first strain sensor can be an embedded-type strain gauge, for example. By acquiring a pattern of change over time in a measurement value from the first strain sensor, a pattern of change over time in an unconfined strain of the concrete to be measured can be obtained.

[0022]

20 A test specimen (confined test specimen) obtained by casting the concrete into the second rectangular frame is configured in a state of being confined by a confining steel member having an extremely low thermal expansion coefficient of less than $1 \times 10^{-6}/^{\circ}\text{C}$. As the confining steel member, an Invar steel member (with a thermal expansion coefficient of about $0.5 \times 10^{-6}/^{\circ}\text{C}$) can be used, for example. A second strain
25 sensor is disposed on the confining steel member. As a detailed example, the second

strain sensor is fixedly disposed on a threaded portion of the confining steel member after the threaded portion has been cut and machined. For example, the second strain sensor can be a strain gauge. By acquiring a pattern of change over time in a measurement value from the second strain sensor, a pattern of change over time in a strain of the confined concrete to be measured can be obtained.

[0023]

The unconfined test specimen and the confined test specimen, together with the plurality of strength test specimens, are housed in the heat-insulated storage container. As the material age elapses, these specimens generate heat due to progress of hydration reaction, which causes a temperature rise inside the storage container. Subsequently, when the progress of hydration reaction reaches a saturation state, a rate of temperature rise in the storage container slows down, and after a lapse of further time, the temperature eventually drops to a level equivalent to an ambient temperature. That is, the unconfined test specimen and the confined test specimen are placed under the same temperature history in the heat-insulated storage container.

[0024]

The measurement value from the first strain sensor corresponds to a value of free strain that reflects strain due to the temperature history and autogenous shrinkage strain. On the other hand, the measurement value from the second strain sensor disposed on the confining steel member is a steel strain that reflects strain due to the temperature history and autogenous shrinkage strain, and corresponds to a value of strain in a confined state. Therefore, a value of confined strain can be obtained based on the measurement value from the first strain sensor and the measurement value from the second strain sensor, and more specifically, based on a difference between the measurement value from the first strain sensor and the measurement value from the

second strain sensor. That is, a pattern of change over time in the confined strain of the concrete to be measured can be obtained.

[0025]

From the relationship between equilibrium of forces between the confining
5 steel member and the concrete and strain compatibility conditions, a confined stress
generated in the concrete can be determined by calculation based on a steel member
ratio (a ratio of the confining steel member in the confined test specimen), a Young's
modulus of the confining steel member, and a value of strain in the confined state. As
described above, the value of strain in the confined state can be determined from the
10 measurement value from the second strain sensor. The Young's modulus of the
confining steel member can be determined from a physical property value of the steel
member used as the confining steel member. The steel member ratio can be determined
from a value of a ratio between an area of an end portion in a longitudinal direction of
the second rectangular frame constituting the confined test unit and a cross-sectional
15 area of the confining steel member.

[0026]

In this way, once a pattern of change over time in the confined strain of the
concrete to be measured and a pattern of change over time in the confined stress are
obtained, an apparent Young's modulus during each of temperature rise and temperature
20 drop can be calculated based on a correlation between the confined stress and the
confined strain. The confined stress and the confined strain exhibit an almost linear
correlation during each of temperature rise and temperature drop. Therefore, by linearly
approximating each correlation using a least-squares method, for example, and deriving
a slope, it is possible to obtain an apparent Young's modulus of the concrete to be
25 measured during each of temperature rise and temperature drop. This apparent Young's

modulus can be regarded as a Young's modulus that takes into account both elastic strain and creep strain under a confined stress that changes from moment to moment.

[0027]

On the other hand, as described above, by executing the Young's modulus measurement test on a plurality of strength test specimens of different material ages, an actual pattern of change over time in a Young's modulus of the concrete to be measured can be obtained. According to the Japan Concrete Institute's "Guidelines for Control of Cracking of Mass Concrete 2016" (hereinafter simply referred to as the "Control Guidelines"), the influence of creep is considered as a decrease in stiffness represented by an effective Young's modulus obtained by multiplying the Young's modulus by a reduction coefficient. In view of this, a reduction coefficient for the Young's modulus of the concrete to be measured (during each of temperature rise and temperature drop) can be calculated from a ratio between the actual Young's modulus obtained by the Young's modulus measurement test and the apparent Young's modulus (during each of temperature rise and temperature drop).

[0028]

According to the Control Guidelines mentioned above, regardless of the type or mixture of cement used in the concrete, a uniformly determined reduction coefficient for the Young's modulus is used for each of temperature rise and temperature drop. In contrast, by using the evaluation device according to the present invention, it is possible to obtain a reduction coefficient for the Young's modulus that is specific to the concrete to be measured. Accordingly, by using this value in numerical analysis, the risk of thermal cracking in mass concrete can be evaluated with higher accuracy.

[0029]

Furthermore, the evaluation device described above is equipped with a

thermometer configured to measure temperature changes inside the storage container.

Therefore, by acquiring a history of changes in a measurement value from the thermometer, an effective material age can be calculated. That is, a relationship between a material age of a strength test specimen removed from the storage container and the effective material age can be obtained.

[0030]

Using information obtained in this way related to a correlation between the material age of the strength test specimen removed from the storage container and the effective material age, various types of correlation information can be obtained. For example, it is possible to obtain a correlation between a pattern of change over time in a compressive strength of the concrete, which is obtained by executing a compressive strength test on strength test specimens removed at each material age, and the effective material age of the concrete. Also, for example, it is possible to obtain a correlation between a pattern of change over time in a splitting tensile strength of the concrete, which is obtained by executing a splitting tensile strength test on strength test specimens removed at each material age, and the effective material age of the concrete.

[0031]

After a lapse of 25 days or more since the unconfined test specimen was placed in the storage container, the unconfined test specimen may be removed from the storage container, and a measurement value from the first strain sensor may be read while applying temperature changes (for example, from an ambient temperature to about 60°C) in an adiabatic environment, to obtain a relationship between the temperature and the measurement value from the first strain sensor.

[0032]

It is considered that the unconfined test specimen after a lapse of 25 days or

more will not experience additional autogenous shrinkage strain associated with a hydration reaction, even if subsequent temperature changes are applied. That is, by applying temperature changes to the unconfined test specimen after a lapse of 25 days or more and obtaining a correlation between the temperature and the measurement value from the first strain sensor, it is possible to obtain information related to a thermal strain of the concrete. Specifically, a thermal expansion coefficient of the concrete can be obtained from a relationship between the temperature and the measurement value from the first strain sensor. Typically, the temperature and the measurement value from the first strain sensor exhibit an almost linear correlation. Therefore, the thermal expansion coefficient of the concrete can be obtained by linearly approximating the correlation between the temperature and the measurement value from the first strain sensor based on a least-squares method and deriving a slope, for example.

[0033]

On the other hand, a measurement value from the first strain sensor provided on the unconfined test specimen in the storage container reflects both a thermal strain based on a temperature history in the storage container and an autogenous shrinkage strain. By multiplying a temperature change value with the unconfined test specimen placed in the storage container by the thermal expansion coefficient of the concrete calculated using the method described above, it is possible to derive a value of the thermal strain that has occurred in the unconfined test specimen in the storage container. Therefore, by subtracting the above value of the thermal strain from the measurement value from the first strain sensor provided on the unconfined test specimen in the storage container, it is possible to obtain a pattern of change over time in an autogenous shrinkage strain of the unconfined test specimen. This autogenous shrinkage strain is an autogenous shrinkage strain of the concrete to be measured.

[0034]

Therefore, based on information related to a correlation between the material age obtained by the method described above and an effective material age, it is possible to obtain a correlation between the effective material age and the autogenous shrinkage strain of the concrete to be measured. The information related to the correlation between the effective material age and the autogenous shrinkage strain of the concrete can be used, in evaluating by 3D-FEM analysis, a risk of thermal cracking in an actual structure constructed using the concrete.

[0035]

In the evaluation device described above, a placement position of the thermometer is not critical as long as a temperature inside the storage container can be measured. However, from the viewpoint of accurately measuring a temperature of the concrete, the thermometer is preferably attached to at least one of the strength test unit, the unconfined test unit, and the confined test unit. Nevertheless, as described above, since the strength test specimens are removed at each material age, in a case where the thermometer is installed in the strength test unit, it is preferable that the thermometer is disposed on a strength test specimen that is to be removed from the storage container at the latest timing.

[0036]

The confined test specimen contains the concrete and the confining steel member, and the confining steel member differs from the concrete in specific heat, thermal conductivity, and heat capacity. On the other hand, the unconfined test specimen does not contain the confining steel member. Therefore, from the viewpoint of accurately measuring the temperature of the concrete, it is more preferable to install the thermometer on the unconfined test specimen than on the confined test specimen.

[0037]

As described above, an autogenous shrinkage strain of the unconfined test specimen is calculated from a value of the thermal strain that has occurred in the unconfined test specimen. Therefore, from the viewpoint of improving calculation accuracy, it is preferable that the thermometer is disposed on the unconfined test specimen. Furthermore, as described above, also from the viewpoint of performing an adiabatic test on the unconfined test specimen removed from the storage container in order to measure the thermal expansion coefficient, it is more preferable that the thermometer is attached to at least the unconfined test unit.

[0038]

The confined test specimen and the unconfined test specimen placed in the storage container are given a temperature history resulting from heat generated by a hydration reaction of the plurality of strength test specimens placed in the same storage container. For example, if the thermometer is disposed on the confined test specimen or the unconfined test specimen, a pattern of temperature changes at each material age can be acquired. Therefore, by performing inverse analysis on a relationship between the material age and a measurement value from the thermometer attached to the confined test specimen or the unconfined test specimen, it is possible to obtain an adiabatic temperature rise property of the concrete to be measured. Information related to the adiabatic temperature rise property of the concrete can be used, in evaluating by 3D-FEM analysis, a risk of thermal cracking in an actual structure constructed using the concrete.

[0039]

Among physical properties of concrete, creep properties are difficult to obtain through experiments or numerical analysis. Therefore, an influence of creep is often

evaluated and used in terms of a reduction coefficient for the Young's modulus.

[0040]

On the other hand, it is not easy to determine a reduction coefficient for the Young's modulus for each concrete. For this reason, at present, a reduction coefficient
5 for the Young's modulus presented in the Japan Concrete Institute's "Guidelines for Control of Cracking of Mass Concrete 2016" (hereinafter simply referred to as the "Control Guidelines") and the like is usually applied to all concretes.

[0041]

In actuality, however, a value of the reduction coefficient for the Young's
10 modulus is expected to vary depending on a type and mixture of cement used in the concrete and the like. Therefore, if a value of the reduction coefficient for the Young's modulus specified in the Control Guidelines is uniformly adopted and a risk of thermal cracking in mass concrete is evaluated based on the value, there is a possibility that an accuracy of the risk evaluation will not be sufficiently ensured.

[0042]

The evaluation device described above can be used, as one means of a method
for estimating values of physical properties of concrete including the reduction
coefficient for the Young's modulus, while taking into account properties of the
concrete to be measured. However, as a means for implementing a method for
20 estimating physical properties of concrete, it is also possible to use a method that does not use the above evaluation device. This estimation method will be described below.

[0043]

This estimation method is a method for estimating physical properties of
concrete to be measured, the method including:

25 a step (a) of placing a plurality of test specimens obtained by casting the

concrete into one or more heat-insulated storage containers that have a temperature history including a temperature rise and a temperature drop;

a step (b) of, each time a predetermined material-age timing is reached, executing a Young's modulus measurement test on a strength test specimen belonging to the plurality of test specimens and calculating a pattern of change over time in a Young's modulus of the concrete;

a step (c) of acquiring a first strain value, which is a measurement value from a first strain sensor attached to an unconfined test specimen obtained by casting the concrete into a frame body in an unconfined state, among the plurality of test specimens;

a step (d) of acquiring a second strain value, which is a measurement value from a second strain sensor attached to a confined test specimen obtained by casting the concrete into a frame body confined by a confining steel member, among the plurality of test specimens;

a step (e) of calculating a pattern of change over time in a confined strain value of the concrete, based on the first strain value and the second strain value;

a step (f) of calculating a pattern of change over time in a confined stress of the concrete, based on a value obtained from the confining steel member included in the confined test specimen and the second strain value;

a step (g) of calculating an apparent Young's modulus during each of temperature rise and temperature drop, based on a correlation between the confined strain value and the confined stress; and

a step (h) of deriving a reduction coefficient for the Young's modulus during each of temperature rise and temperature drop, based on a ratio between the Young's modulus obtained in the step (b) and the apparent Young's modulus obtained in the step

(g).

[0044]

Here, as the concrete to be evaluated, concrete that is actually poured in the field may be used, or concrete supplied from a concrete plant and made of the same material as concrete to be poured in the field may be used.

[0045]

For example, each time a predetermined material-age timing is reached, a strength test specimen is removed from the storage container and a Young's modulus measurement test is executed on the strength test specimen, thereby calculating a pattern of change over time in a Young's modulus of the concrete. The Young's modulus measurement test is performed by a method complying with JIS A 1149:2017 "Method of test for static modulus of elasticity of concrete", for example. As a more specific example, after each lapse of material ages of 1, 3, 7, 14, and 28 days, a strength test specimen is removed from the storage container and subjected to the above test.

[0046]

It is acceptable to perform the same test on a plurality of strength test specimens of the same material age and to use a value (for example, an average value) obtained by calculation based on resultant measurements as a measurement value obtained from the test result.

[0047]

The unconfined test specimen is a test specimen obtained by casting the concrete into a frame body in an unconfined state with the first strain sensor attached. More specifically, the unconfined test specimen is obtained by casting the concrete into the frame body in an unconfined state with the first strain sensor placed inside so that the first strain sensor is embedded. For example, the first strain sensor can be an

embedded-type strain gauge. In the step (c), by acquiring a pattern of change over time in a measurement value from the first strain sensor, a pattern of change over time in an unconfined strain of the concrete to be measured can be obtained.

[0048]

5 The confined test specimen is a test specimen obtained by casting the concrete into a frame body confined by the confining steel member with the second strain sensor attached. More specifically, the confined test specimen is obtained by casting the concrete so as to embed the confining steel member with the second strain sensor fixedly attached to the confining steel member.

10 **[0049]**

 As the confining steel member, a material having an extremely low thermal expansion coefficient can be advantageously used, and is preferably a material having a thermal expansion coefficient of less than $1 \times 10^{-6}/^{\circ}\text{C}$. Such a confining steel member may be, for example, an Invar steel member (with a thermal expansion coefficient of
15 about $0.5 \times 10^{-6}/^{\circ}\text{C}$).

[0050]

 In a detailed example, a threaded portion of the confining steel member is cut and machined, and then the second strain sensor is fixedly disposed on the processed portion. For example, a strain gauge can be used as the second strain sensor. In the step
20 (d), by acquiring a pattern of change over time in a measurement value from the second strain sensor, a pattern of change over time in a strain of the concrete to be measured in a confined state can be obtained.

[0051]

 The unconfined test specimen and the confined test specimen are placed under
25 the same temperature history in the heat-insulated storage container.

[0052]

A measurement value from the first strain sensor corresponds to a value of free strain that reflects strain due to the temperature history and autogenous shrinkage strain. On the other hand, a measurement value from the second strain sensor disposed on the
5 confining steel member is a steel strain that reflects strain due to the temperature history and autogenous shrinkage strain and corresponds to a value of strain in a confined state. Therefore, in the step (e), a value of confined strain can be obtained based on the measurement value from the first strain sensor and the measurement value from the second strain sensor. As a specific method for the step (e), a method can be used which
10 calculates a difference between the measurement value from the first strain sensor and the measurement value from the second strain sensor. Through the step (e), a pattern of change over time in a confined strain of the concrete to be measured can be obtained.

[0053]

In the step (f), the confined stress generated in the concrete is calculated from
15 the second strain value obtained in the step (d), that is, the value of the strain in the confined state, by using the relationship concerning equilibrium of forces between the confining steel member and the concrete and strain compatibility conditions. More specifically, the confined stress generated in the concrete can be calculated by a computation based on a ratio of the confining steel member in the confined test
20 specimen (steel member ratio), a Young's modulus of the confining steel member, and the value of the strain in the confined state. The Young's modulus of the confining steel member can be obtained from physical property values of the steel member used as the confining steel member. As the steel member ratio, for example, a value of a ratio between an area of an end portion related to a direction in which the confining steel
25 member extends of a frame body constituting the confined test specimen and a

cross-sectional area of the confining steel member can be used.

[0054]

In this way, once a pattern of change over time in the confined strain of the concrete to be measured and a pattern of change over time in the confined stress of the concrete to be measured are obtained, in the step (g), an apparent Young's modulus during each of temperature rise and temperature drop is calculated based on a correlation between the confined stress and the confined strain. The confined stress and the confined strain exhibit an almost linear correlation during each of temperature rise and temperature drop. Therefore, by linearly approximating each correlation using, for example, a least-squares method and deriving a slope, it is possible to obtain an apparent Young's modulus of the concrete to be measured during each of temperature rise and temperature drop. The apparent Young's modulus can be regarded as a Young's modulus that takes into account both elastic strain and creep strain under a confined stress that varies with time.

[0055]

As described above, in the step (b), by executing a Young's modulus measurement test on a plurality of strength test specimens having different material ages, an actual pattern of change over time in the Young's modulus of the concrete to be measured can be obtained. According to the Control Guidelines, an influence of creep is considered as a decrease in stiffness represented by an effective Young's modulus obtained by multiplying the Young's modulus by a reduction coefficient. Accordingly, in the step (h), a reduction coefficient for the Young's modulus (during each of temperature rise and temperature drop) of the concrete to be measured is calculated based on a ratio between an actual Young's modulus obtained by the Young's modulus measurement test and the apparent Young's modulus (during each of temperature rise

and temperature drop). A reduction coefficient for the Young's modulus calculated in this way has a value that reflects properties specific to the concrete to be measured. Therefore, by using this value in numerical analysis, for example, it is possible to evaluate, with higher accuracy, a risk of thermal cracking in mass concrete.

5 **[0056]**

The step (a) may be a step of placing the plurality of strength test specimens, the one or more unconfined test specimens, and the one or more confined test specimens in the same storage container.

10 The temperature history may be obtained based on the heat generated from the plurality of strength test specimens placed in the storage container.

[0057]

In this case, the unconfined test specimen and the confined test specimen are stored, together with the plurality of strength test specimens, in the same heat-insulated storage container. As material age elapses, these specimens generate heat due to
15 progress of a hydration reaction, and this generation of heat causes a temperature rise in the storage container. Subsequently, when the hydration reaction reaches a saturated state, a rate of the temperature rise in the storage container decreases, and after a further lapse of time, the temperature eventually drops to a level approximately equal to ambient temperature. That is, the unconfined test specimen and the confined test
20 specimen are placed under the same temperature history in the heat-insulated storage container.

[0058]

Therefore, according to the above method, it is not necessary to prepare in advance a plurality of storage containers to each of which the same temperature history
25 is applied, and thus a preparation step for the estimation can be simplified.

[Advantageous Effects of Invention]

[0059]

According to the evaluation device of the present invention, it is possible, by a
5 simple method, to obtain various physical property values of concrete, while using
concrete that is made of the same material as concrete to be used at a site.

[Brief Description of Drawings]

[0060]

10 FIG. 1 is a schematic perspective view of an external appearance and a
configuration of an embodiment of an evaluation device according to the present
invention.

FIG. 2 is a schematic cross-sectional view of the evaluation device shown in
FIG. 1.

15 FIG. 3 is a schematic plan view of the evaluation device shown in FIG. 1 with
a lid portion removed.

FIG. 4 is a schematic plan view of a state in which strength test specimens are
removed from the state shown in FIG. 3.

20 FIG. 5 is a schematic perspective view of a configuration of a strength test
specimen.

FIG. 6 is a schematic plan view of a configuration of an unconfined test
specimen.

FIG. 7 is a schematic plan view of a configuration of a confined test specimen.

25 FIG. 8 is a graph schematically showing a correlation between a number of
elapsed days and a Young's modulus.

FIG. 9 is a graph showing a correlation between an effective material age and a Young's modulus, measured using the concrete used in Example 1.

FIG. 10 is a graph showing a correlation between an effective material age and a compressive strength, measured using the concrete used in Example 1.

5 FIG. 11 is a graph showing a correlation between a compressive strength and a Young's modulus, measured using the concrete used in Example 1.

FIG. 12 is a graph showing a correlation between a compressive strength and a splitting tensile strength, measured using the concrete used in Example 1.

10 FIG. 13 is a graph schematically showing a pattern of change over time in measurement values from a first strain sensor and a second strain sensor.

FIG. 14 is a graph showing a pattern of change over time in measurement values from the first strain sensor and the second strain sensor, measured using the concrete used in Example 1.

15 FIG. 15 is a graph schematically showing a pattern of change over time in a confined stress.

FIG. 16 is a graph schematically showing a correlation between a confined stress and a confined strain.

20 FIG. 17 is a graph showing a correlation between a confined stress and a confined strain, calculated based on the measurement values from the first strain sensor and the second strain sensor, measured using the concrete used in Example 1.

25 FIG. 18 is a graph showing a correlation between a reduction coefficient for a Young's modulus and an effective material age, the graph being derived based on a correlation between a confined stress and a confined strain measured using the concrete used in Example 1, and a correlation between the effective material age and the Young's modulus.

FIG. 19 is a graph showing a relationship between a measurement value from the first strain sensor and a temperature during execution of an adiabatic test on concrete used in Example 1.

FIG. 20 is a graph showing a relationship between an autogenous shrinkage strain and an effective material age, derived from measurement values obtained using concrete used in Example 1.

FIG. 21 is a graph schematically showing a relationship between a material age of concrete to be measured that is placed in a storage container and an amount of temperature rise.

FIG. 22 is a graph schematically showing adiabatic temperature rise properties of the concrete to be measured, obtained by inverse analysis of results shown in FIG. 21

[Description of Embodiments]

[0061]

<First Embodiment>

The evaluation device according to the present invention is a device for evaluating properties of concrete to be measured. More specifically, the evaluation device is used in a state where a plurality of test specimens, which are obtained by pouring concrete to be measured into a predetermined area, are stored inside the evaluation device.

[0062]

Hereinafter, embodiments of the evaluation device according to the present invention and embodiments of a method for using the evaluation device will be described with reference to the drawings as appropriate. However, the drawings referred to below are schematic representations, and dimensional ratios shown in the drawings

do not necessarily match actual dimensional ratios. Furthermore, the dimensional ratios do not necessarily match between the drawings.

[0063]

[Configuration of Evaluation Device]

5 FIG. 1 is a schematic perspective view schematically showing an external appearance of the evaluation device. The evaluation device 1 includes a lid portion 2 and a storage container 3. Both the lid portion 2 and the storage container 3 are made of a heat-insulating material, for example, foamed polystyrene. The lid portion 2 is removable from the storage container 3.

10 **[0064]**

 In the following description, an X-Y-Z coordinate system shown in FIG. 1 will be referenced. Furthermore, in the following description, when expressing directions with a distinction between positive and negative directions, a positive or negative sign is added, such as “+Z direction” or “-Z direction”. When expressing directions without
15 distinguishing between positive and negative directions, the direction is simply referred to as “Z direction”. That is, in this specification, when simply referred to as “Z direction”, both the “+Z direction” and the “-Z direction” are included. Typically, the +Z direction is a vertically upward direction.

[0065]

20 FIG. 2 is a schematic cross-sectional view of the evaluation device 1 shown in FIG. 1, obtained by cutting the evaluation device 1 along an X-Z plane at a predetermined Y-coordinate position. FIG. 3 is a schematic plan view of the evaluation device 1 shown in FIG. 1 from which the lid portion 2 is removed, as seen in the -Z direction from a +Z side.

25 **[0066]**

As shown in FIGS. 2 and 3, the storage container 3 has a bottom portion 3b disposed at a position facing the lid portion 2 in the Z direction, and side portions 3a that cover, from four sides, a region above the bottom portion 3b. Test specimens (10, 20, 30) are placed inside a region surrounded by the side portions 3a and the bottom portion 3b.

[0067]

The evaluation device 1 is used in a state where strength test specimens 10, unconfined test specimens 20, and confined test specimens 30 are placed in the storage container 3. As shown in FIGS. 2 and 3, in the evaluation device 1 of the present embodiment, a plurality of strength test specimens 10 are placed closer to the lid portion 2 than the unconfined test specimens 20 and the confined test specimens 30. FIG. 3 illustrates an example in which thirty strength test specimens 10 are placed in the evaluation device 1.

[0068]

FIG. 4 is a schematic plan view of the evaluation device 1 as seen from a +Z side in a -Z direction, with the plurality of strength test specimens 10 removed from the state shown in FIG. 2. As shown in FIGS. 2 and 4, in the evaluation device 1 of the present embodiment, the unconfined test specimens 20 and the confined test specimens 30 are positioned on a bottom-portion-3b side and are arranged along a surface (X-Y plane) of the bottom portion 3b. FIG. 4 illustrates an example in which two unconfined test specimens 20 and two confined test specimens 30 are placed in the evaluation device 1.

[0069]

FIG. 5 is a schematic perspective view of a configuration of the strength test specimen 10. The strength test specimen 10 has a cylindrical tubular body 11 made of

tinplate or plastic, and is formed by pouring concrete to be measured into an internal space 12 of the tubular body 11, for example. Dimensions of the tubular body 11 can be arbitrary, and, as one example, the tubular body 11 has a diameter of 10 cm and a height of 20 cm. FIG. 3 shows a state in which thirty strength test specimens 10, each formed by pouring concrete of the same material as the concrete to be measured into the internal space 12 of a tubular body 11 having the same dimensions, are placed in the storage container 3. The tubular body 11 corresponds to a “first cylindrical mold”.

[0070]

As shown in FIGS. 2 and 3, in order to ensure thermal insulation of the internal spaces 12 of the tubular bodies 11, a heat-insulating filler 6 made of foamed beads, foamed polystyrene molded into a shape of the internal space 12, spray-type foamed polyurethane, rock wool, glass wool, or the like is filled in spaces between the plurality of strength test specimens 10.

[0071]

FIG. 6 is a schematic plan view of a configuration of the unconfined test specimen 20. The unconfined test specimen 20 has a bottomed rectangular frame body 21 made of wood, plywood, or the like, and a first strain sensor 25 is disposed in an internal space 23 of the frame body 21. The unconfined test specimen 20 is formed by pouring concrete to be measured into the internal space 23 of the frame body 21 so as to embed the first strain sensor 25. The first strain sensor 25 can be an embedded-type strain gauge, for example. The frame body 21 corresponds to a “first rectangular frame”.

[0072]

Dimensions of the frame body 21 can be arbitrary, and, as one example, the frame body 21 has a rectangular parallelepiped shape of 10 cm × 10 cm × 80 cm.

[0073]

From the viewpoint of suppressing deformation of the concrete by the frame body 21, a buffer board made of polystyrene or the like may be attached to side surfaces in a longitudinal direction of the frame body 21, and a buffer film made of polyester or the like may be attached to side surfaces in a short-side direction and to a bottom surface.

[0074]

In the example shown in FIG. 6, a signal wire 27 is attached to the first strain sensor 25 so that a measurement value from the first strain sensor 25 can be read continuously or intermittently. However, as long as a measurement value from the first strain sensor 25 can be read continuously or intermittently, a connection of the first strain sensor 25 is not limited to a wired connection and may be a wireless connection.

[0075]

The first strain sensor 25 is preferably an embedded-type strain gauge equipped with a temperature-measuring function. If the first strain sensor 25 does not have a temperature-measuring function, the frame body 21 may be equipped with a thermocouple (not shown) so that a temperature of the unconfined test specimen 20 can be measured.

[0076]

FIG. 7 is a schematic plan view of a configuration of the confined test specimen 30. The confined test specimen 30 has a bottomed rectangular frame body formed by a pair of side plates 31 arranged opposite each other in a short-side direction, a pair of end plates 32 arranged opposite each other in a longitudinal direction, and a bottom plate (not shown). This frame body corresponds to a “second rectangular frame”.

[0077]

The pair of end plates 32 are fixedly coupled to each other by a confining steel member 34. The end plates 32 and the confining steel member 34 are fixed together by welding, for example. The side plates 31 and the bottom plate are made of wood, plywood, or the like, for example. The end plates 32 and the confining steel member 34 are made of a steel material having an extremely low thermal expansion coefficient of less than $1 \times 10^{-6}/^{\circ}\text{C}$. As a specific example, the end plates 32 and the confining steel member 34 are made of Invar steel, tungsten, or the like, and preferably of Invar steel.

[0078]

In the confined test specimen 30, a steel member ratio of the confining steel member 34 is preferably from 0.5% to 6%. Here, the steel member ratio of the confining steel member 34 can be defined as a value of a ratio of a cross-sectional area of the confining steel member 34 to an area of the end plate 32.

[0079]

A second strain sensor 35 is disposed on the confining steel member 34. The second strain sensor 35 can be a strain gauge, for example. In the example shown in FIG. 7, a thermometer 36 constituted of a thermocouple is attached to the confining steel member 34. However, whether the confined test specimen 30 has the thermometer 36 or not is optional.

[0080]

External dimensions of a bottomed frame body formed by the side plates 31, the end plates 32, and the bottom plate can be arbitrary, and, for example, the bottomed frame body has a rectangular parallelepiped shape of $10\text{ cm} \times 10\text{ cm} \times 80\text{ cm}$. The confined test specimen 30 is formed by pouring concrete to be measured into an internal space 33 of the bottomed frame body so as to embed the confining steel member 34.

[0081]

The side plates 31 and the bottom plate may have a buffer film made of polyester or the like attached thereto. The end plates 32 are provided for the purpose of receiving an expansion force of the concrete caused by heat generation in an initial stage after the concrete is poured, if the concrete expands due to the heat generation, and of accurately measuring an expansion stress.

[0082]

In the example shown in FIG. 7, a signal wire 37 is attached to the second strain sensor 35 so that a measurement value from the second strain sensor 35 can be read continuously or intermittently. However, as long as a measurement value from the second strain sensor 35 can be read continuously or intermittently, a connection of the second strain sensor 35 is not limited to a wired connection and may be a wireless connection. Further, temperature information measured by the thermometer 36 may also be read continuously or intermittently, similarly to the measurement value from the second strain sensor 35.

[0083]

As described above, before the concrete is poured, the evaluation device 1 has, inside the storage container 3 that constitutes a heat-insulated storage container, a plurality of tubular bodies 11, a frame body 21 in which the first strain sensor 25 is disposed in the internal space 23, and a frame body (31, 32) in which the confining steel member 34 with the second strain sensor 35 attached thereto is fixed in the internal space 33.

[0084]

The tubular body 11 constitutes the strength test unit, and the strength test specimen 10 is formed by pouring concrete to be measured into the internal space 12 of the tubular body 11. The frame body 21 and the first strain sensor 25 constitute the

unconfined test unit, and the unconfined test specimen 20 is formed by pouring concrete to be measured into the internal space 23 of the frame body 21. The frame body (31, 32), the confining steel member 34, and the second strain sensor 35 constitute the confined test unit, and the confined test specimen 30 is formed by pouring concrete to be measured into the internal space 33 of the frame body (31, 32).

[0085]

Referring to FIG. 4, the unconfined test specimens 20 and the confined test specimens 30 are arranged in a direction of the X-Y plane so as to substantially close an internal space surrounded by side portions of the storage container 3. External dimensions of the storage container 3 may be set as appropriate according to external dimensions of the frame body 21 constituting the unconfined test specimen 20 and external dimensions of the frame body (31, 32) constituting the confined test specimen 30. However, when the unconfined test specimens 20 and the confined test specimens 30 are arranged without gaps in the direction of the X-Y plane, if a gap occurs between the side portions 3a of the storage container 3 and each of the test specimens (20, 30), the gap may be filled with the heat-insulating filler 6.

[0086]

[How to Use Evaluation Device]

When using the evaluation device 1, test specimens (strength test specimens 10, unconfined test specimens 20, and confined test specimens 30), which are formed by pouring concrete to be measured into respective test units, are placed in an inner space of the storage container 3 of the evaluation device 1. The lid portion 2 is then arranged so as to cover an upper side of the storage container 3.

[0087]

More specifically, the unconfined test specimens 20 and the confined test

specimens 30 are placed on a surface of the bottom portion 3b. Then, the plurality of strength test specimens 10 are arranged on upper surfaces of these test specimens (20, 30) along a direction of an X-Y plane. The unconfined test specimens 20 and the confined test specimens 30 may have a buffer film made of polyester or the like
5 attached to open +Z-side surfaces thereof, for example.

[0088]

After the test specimens (10, 20, 30) are placed in the evaluation device 1, the strength test specimens 10 are removed each time a predetermined material-age timing is reached. After the strength test specimens 10 are removed, the heat-insulating filler 6
10 is preferably placed in the storage container 3 so as to fill a gap created by removal of the strength test specimens 10.

[0089]

For example, the strength test specimens 10 are removed from the storage container 3 at each lapse of 1, 3, 7, 14, and 28 days of material age. By subjecting the
15 removed strength test specimens 10 at each material age to a Young's modulus measurement test, a relationship between a Young's modulus and a material age of the concrete to be measured can be obtained (see FIG. 8, for example). The Young's modulus measurement test can be performed by a method complying with JIS A 1149:2017 "Method of test for static modulus of elasticity of concrete", for example.

20 **[0090]**

As described above, at least one of the unconfined test specimen 20 and the confined test specimen 30 placed in the storage container 3 is equipped with a temperature-measuring function (thermometer). Since an internal space of the storage container 3 is covered with a heat-insulating member, for example, a temperature
25 history read from the first strain sensor 25, which is an embedded-type strain gauge

equipped with a temperature-measuring function and disposed in the unconfined test specimen 20, can be regarded as a temperature history in the storage container 3. Also, for example, a temperature history read from the thermometer 36 disposed in the confined test specimen 30 can be regarded as the temperature history in the storage container 3. As another example, a separate thermometer may be disposed in the storage container 3, and in this case, a temperature history read from the thermometer can be regarded as the temperature history in the storage container 3.

[0091]

That is, according to the evaluation device 1, information related to a temperature history in the storage container 3 can be obtained. Based on the information related to the temperature history, a relationship between a placement period (actual material age) of a test specimen placed in the storage container 3 and an effective material age can be obtained. As one example, an effective material age t_e is calculated based on an Arrhenius law of Equation (1) below, as specified in crack-control guidelines for mass concrete.

[0092]

[Math. 1]

$$t_e = \sum_{i=1}^n \Delta t_i \cdot \exp \left\{ 13.65 - \frac{4000}{273 + T(\Delta t_i)} \right\} \quad (1)$$

[0093]

In Equation (1), Δt_i represents the period (days) during which the given concrete temperature persists, and $T(\Delta t_i)$ represents the concrete temperature (°C) that persists during Δt_i .

[0094]

As an example, concrete containing the materials shown in Table 1 in a mixture proportion shown in Table 2 was poured into each test unit as concrete to be measured, thereby generating test specimens (10, 20, 30), which were then placed in the evaluation device 1.

5 [0095]

[Table 1]

Materials

Material	Symbol	Physical properties, etc.
Cement	C	Ordinary Portland cement Density: 3.16 g/cm ³ Specific surface area: 3310 cm ² /g
Expansion agent	EX	Lime-based expansion agent Density: 3.14 g/cm ³
Fine aggregate	S	Land sand from Omaezaki Surface dry density: 2.59 g/cm ³ Water absorption rate: 1.63%
Coarse aggregate	G	Crushed stone from Iwase Maximum dimension: 20 mm Surface dry density: 2.64 g/cm ³ Water absorption rate: 0.84%
AE water-reducing agent	SP	Polycarboxylic acid-based Density: 1.09 g/cm ³

[0096]

[Table 2]

10 Mixture of concrete

Slump (cm)	Air content (%)	W/B (%)	s/a (%)	Unit amount (kg/m ³)					
				W	C	Ex	S	G	Sp
15 ± 2.5	4.5 ± 1.5	55	47	175	288	30	830	951	0.636

[0097]

The test specimens were placed in the evaluation device 1 using the concrete used in Example 1, and a relationship between a material age (placement period) in the evaluation device 1 and an effective material age was obtained based on a temperature

15 history measured by the thermometer. Then, at each arrival of a predetermined

material-age timing, a strength test specimen 10 removed from the storage container 3 was subjected to a Young's modulus measurement test, and a correlation between a measured Young's modulus and the effective material age was obtained. FIG. 9 shows a correlation between the Young's modulus and the effective material age.

5 **[0098]**

The Young's modulus measurement test and a compressive strength test can be performed in parallel. Therefore, by performing the compressive strength test on the strength test specimen 10 removed at each material age, it is possible to obtain a relationship between a compressive strength and a material age of the concrete to be measured. The compressive strength test is performed by a method complying with JIS A 1108:2018 "Method of test for compressive strength of concrete", for example. Furthermore, since the relationship between the material age and the effective material age can be obtained as described above, a relationship between the compressive strength and the effective material age can also be obtained. FIG. 10 is a graph showing a correlation between the compressive strength and the effective material age measured using the concrete used in Example 1. In addition, a correlation between the Young's modulus and the compressive strength may be derived based on the results shown in FIGS. 9 and 10. FIG. 11 is a graph showing a correlation between the compressive strength and the Young's modulus measured using the concrete used in Example 1.

20 **[0099]**

A strength test specimen 10 may be removed from the storage container 3 at the same material age as a material age for the compressive strength test, and the removed strength test specimen 10 at each material age may then be subjected to a splitting tensile strength test. In this case, from the viewpoint of performing the splitting tensile strength test and the Young's modulus measurement test (and the compressive

strength test) on strength test specimens 10 of the same material age, it is preferable to place the strength test specimens 10 in a number equal to or greater than twice the number of types of material age for testing in the evaluation device 1.

[0100]

5 The splitting tensile strength test is performed by a method complying with JIS A 1113:2018 “Method of test for splitting tensile strength of concrete”, for example. As described above, since the relationship between the material age and the effective material age can be obtained, a relationship between the splitting tensile strength and the effective material age can also be obtained.

10 **[0101]**

 Therefore, by comparing a compressive strength and a splitting tensile strength at the same effective material age, it is also possible to obtain a relationship between the compressive strength and the splitting tensile strength. FIG. 12 is a graph showing a correlation between the compressive strength and the splitting tensile strength measured
15 using the concrete used in Example 1.

[0102]

 The storage container 3 is kept in a heat-insulated state, and a plurality of test specimens (10, 20, 30) are placed inside the storage container 3. As material age of these test specimens (10, 20, 30) elapses, a hydration reaction progresses and generates
20 heat, and this generation of heat causes a temperature in the storage container 3 to rise. Subsequently, when progress of the hydration reaction reaches a saturated state, a rate of temperature rise in the storage container 3 decreases, and after a further lapse of time, the temperature drops to a level approximately equal to ambient temperature. That is, the unconfined test specimen 20 and the confined test specimen 30 are placed under the
25 same temperature history in the heat-insulated storage container 3.

[0103]

Change over time in a strain value read from the first strain sensor 25 disposed in the unconfined test specimen 20 corresponds to change over time in an unconfined strain of the concrete to be measured under the temperature history described above.

5 Change over time in a strain value read from the second strain sensor 35 disposed in the confined test specimen 30 corresponds to change over time in a confined strain of the concrete to be measured under the temperature history described above. FIG. 13 is a graph schematically showing a pattern of change over time in a measurement value from the first strain sensor 25 and a pattern of change over time in a measurement value
10 from the second strain sensor 35. FIG. 14 is a graph showing a pattern of change over time in a measurement value S1 from the first strain sensor 25 disposed in the unconfined test specimen 20 using the concrete used in Example 1, and a pattern of change over time in a measurement value S2 from the second strain sensor 35 disposed in the confined test specimen 30 using the concrete used in Example 1.

[0104]

The measurement value S1 from the first strain sensor 25 corresponds to a value of free strain that reflects strain associated with the temperature history and autogenous shrinkage strain. On the other hand, the measurement value S2 from the second strain sensor 35 corresponds to a value of strain in a confined state that reflects
20 strain associated with the temperature history and autogenous shrinkage strain. Therefore, by calculating a difference value S3 between the measurement value S1 from the first strain sensor 25 and the measurement value S2 from the second strain sensor 35, a pattern of change over time in a confined strain ϵ_s of the concrete to be measured can be obtained.

[0105]

Furthermore, based on a relationship of equilibrium of forces between the confining steel member 34 and the concrete poured into the confined test specimen 30, a confined stress can be obtained. For example, a confined stress F can be calculated by Equation (2) below. In Equation (2), E_s corresponds to a Young's modulus of the confining steel member 34, p corresponds to a steel member ratio of the confining steel member 34 in the confined test specimen 30, and s_2 corresponds to the measurement value from the second strain sensor 35 disposed in the confined test specimen 30. Note that, in Equation (2), tensile stress is expressed as a positive value and compressive stress is expressed as a negative value.

$$F = -E_s \cdot p \cdot s_2 \quad \dots (2)$$

[0106]

For example, by performing a calculation of Equation (2) above, it is possible to obtain a pattern of change over time in the confined stress F in the concrete poured into the confined test specimen 30. FIG. 15 is a graph schematically showing a pattern of change over time in the confined stress F .

[0107]

Thus obtained, a pattern of change over time in the confined stress F and a pattern of change over time in the confined strain ε_s exhibit a correlation with each other. FIG. 16 is a graph schematically showing a correlation between the confined stress and the confined strain.

[0108]

As schematically shown in FIG. 16, the confined stress and the confined strain exhibit an approximately linear correlation during each of temperature rise (curve Eca1) and temperature drop (curve Eca2). Therefore, by linearly approximating each correlation using a least-squares method, for example, and deriving a slope, it is

possible to obtain an apparent Young's modulus of the concrete to be measured during each of temperature rise and temperature drop. The apparent Young's modulus can be regarded as a Young's modulus that takes into account both elastic strain and creep strain under a confined stress that varies with time.

5 **[0109]**

FIG. 17 is a graph showing a correlation between the confined stress and the confined strain, calculated based on the results shown in FIG. 14. In the case of the results shown in FIG. 17, an apparent Young's modulus of the concrete to be measured during temperature rise is obtained as 4.8 kN/mm^2 , and an apparent Young's modulus of
10 the concrete to be measured during temperature drop is obtained as 29.4 kN/mm^2 .

[0110]

On the other hand, as described above with reference to FIG. 9, by performing the Young's modulus measurement test on the strength test specimen 10 removed from the evaluation device 1 at each material age, a pattern of change over time in a Young's
15 modulus of the concrete to be measured can be obtained. Using a ratio between the measured Young's modulus and an apparent Young's modulus derived by the calculation method described above, it is possible to determine a reduction coefficient for the Young's modulus of the concrete to be measured. FIG. 18 is a graph showing a relationship between the reduction coefficient for the Young's modulus calculated by
20 the above calculation and the effective material age. In practice, an average value of reduction coefficients for the Young's modulus over a temperature-rise period can be used as a reduction coefficient for the Young's modulus of the concrete to be measured during temperature rise. Similarly, an average value of reduction coefficients for the Young's modulus over a temperature-drop period can be used as a reduction coefficient
25 for the Young's modulus of the concrete to be measured during temperature drop. In the

example shown in FIG. 18, a reduction coefficient for the Young's modulus of the concrete to be measured is obtained as 0.28 during temperature rise and 1.00 during temperature drop.

[0111]

5 Alternatively, after a lapse of a period of time during which a hydration reaction is considered to have progressed sufficiently, the unconfined test specimen 20 may be removed from the storage container 3 and subjected to a separate adiabatic test. As timing for removing the unconfined test specimen 20 from the storage container 3, a timing at which a temperature of the storage container 3 has decreased to a level at
10 which a reading of a thermometer disposed in the storage container 3 becomes approximately equal to a temperature of an atmosphere in which the storage container 3 is disposed can be used. For example, the timing can be after a lapse of 25 days or more.

[0112]

 The unconfined test specimen 20 is placed in a constant-temperature chamber
15 programmed so that a preset temperature history within a range of 20°C to 60°C is generated, for example, and a correlation between a measurement value from the first strain sensor 25 attached to the unconfined test specimen 20 and a temperature is obtained.

[0113]

20 An example of the temperature history is as follows:

 20°C (held for three hours) → temperature rise at 5°C /hour → 30°C (held for three hours) → temperature rise at 5°C /hour → 40°C (held for three hours) → temperature rise at 4°C /hour → 50°C (held for three hours) → temperature rise at 5°C /hour → 60°C (held for three hours) → temperature drop at 5°C /hour → 50°C (held for
25 three hours) → temperature drop at 5°C /hour → 40°C (held for three hours) →

temperature drop at 5°C /hour → 30°C (held for three hours) → temperature drop at 5°C /hour → 20°C (held for three hours).

[0114]

With the above temperature rise and temperature drop taken as one cycle, two cycles of temperature change are applied to the unconfined test specimen 20, for example. Then, under the above temperature history, at each time period in which the temperature is held (for example, 20°C, 30°C, 40°C, 50°C, and 60°C), a measurement value from the first strain sensor 25 is read at a time when a reading of a thermometer mounted on the unconfined test specimen 20 becomes stable.

[0115]

FIG. 19 is a graph showing a relationship between a measurement value from the first strain sensor 25 and a temperature when the above-described adiabatic test was performed on the unconfined test specimen 20 using the concrete used in Example 1.

[0116]

As described above, the adiabatic test was performed on the unconfined test specimen 20 after a lapse of a period of time during which a hydration reaction is considered to have progressed sufficiently. Therefore, even when a temperature change is applied to the unconfined test specimen 20 in the adiabatic test, it is considered that no additional autogenous shrinkage strain associated with the hydration reaction occurs in the concrete poured into the unconfined test specimen 20. Accordingly, a correlation between a measurement value from the first strain sensor 25 and a temperature shown in FIG. 19 can be regarded as information that reflects thermal strain of the concrete poured into the unconfined test specimen 20. As shown in FIG. 19, since the temperature and the measurement value from the first strain sensor 25 exhibit an approximately linear correlation, by linearly approximating the two based on, for

example, a least-squares method and deriving a slope, a thermal expansion coefficient of the concrete poured into the unconfined test specimen 20, that is, of the concrete to be measured, can be obtained.

[0117]

5 A measurement value S1 (see FIGS. 13 and 14) from the first strain sensor 25 of the unconfined test specimen 20 placed in the storage container 3 reflects both thermal strain and autogenous shrinkage strain based on a temperature history in the storage container 3. As described above in relation to derivation of an effective material age, the evaluation device 1 can provide information on the temperature history in the storage container 3. Therefore, by multiplying temperature-change values obtained from the temperature history by the thermal expansion coefficient of the concrete to be measured, it is possible to obtain a value of thermal strain of the concrete to be measured based on the temperature history in the storage container 3. By subtracting the value of the thermal strain from the measurement value S1 from the first strain sensor 10 25 of the unconfined test specimen 20 placed in the storage container 3, it is possible to obtain a pattern of change over time in an autogenous shrinkage strain of the unconfined test specimen 20, that is, a pattern of change over time in an autogenous shrinkage strain of the concrete to be measured.

[0118]

20 As described above, based on temperature changes in the storage container 3, a correlation between a material age and an effective material age in the storage container 3 is obtained. Therefore, a correlation between an autogenous shrinkage strain of the concrete to be measured and an effective material age of the concrete can be obtained.

FIG. 20 is a graph showing a correlation between an autogenous shrinkage strain and an effective material age of the concrete in Example 1, which is derived based on the 25

results shown in FIGS. 14 and 19. Information on a correlation between the effective material age and the autogenous shrinkage strain of the concrete obtained by the above method can be used to evaluate, by 3D-FEM analysis, a risk of thermal cracking in actual structures constructed using the concrete.

5 **[0119]**

Furthermore, as described above, since temperature changes in the storage container 3 are obtained, a relationship T_a between a material age of the concrete to be measured and an amount of temperature rise can be obtained, as schematically shown in FIG. 21, for example. Therefore, by performing inverse analysis on the relationship T_a ,
10 it is possible to obtain an adiabatic temperature rise characteristic T_b of the concrete to be measured, as schematically shown in FIG. 22.

[0120]

As described above, according to the evaluation device 1 of the present invention, it is possible to directly obtain various physical properties of the concrete to
15 be measured. In addition, by performing calculation processing using the obtained physical properties, even more physical properties can be obtained. By performing numerical analysis using many physical properties obtained in this way, it is possible to evaluate, with high accuracy, a risk of thermal cracking in structures (mass concrete) made of the concrete to be measured.

20 **[0121]**

<Second Embodiment>

The present embodiment corresponds to an embodiment for estimating a reduction coefficient for a Young's modulus of concrete to be measured while using a predetermined evaluation device that evaluates properties of the concrete. In detail, the
25 evaluation device is used in a state where a plurality of test specimens, each formed by

pouring concrete to be measured into a predetermined area, are stored inside. In evaluating properties of the concrete to be measured, the evaluation device 1 in the first embodiment can be used. Description of the evaluation device 1 and its usage is omitted, since it would be duplicated.

5 **[0122]**

As described above, the evaluation device 1 makes it possible to obtain various physical properties of the concrete to be measured, including a reduction coefficient for the Young's modulus. By performing numerical analysis using many physical properties thus obtained, it is possible to evaluate, with high accuracy, a risk of thermal cracking in
10 structures (mass concrete) made of the concrete to be measured.

[0123]

In the first embodiment, the evaluation device 1 is also used to derive physical properties of the concrete other than the reduction coefficient for the Young's modulus of the concrete. However, it is not always necessary to derive physical properties other
15 than the reduction coefficient for the Young's modulus of the concrete and physical properties necessary to derive the reduction coefficient.

[0124]

The method for placing the strength test specimens 10, the unconfined test specimens 20, and the confined test specimens 30 in the storage container 3 of the
20 evaluation device 1 described above in the first embodiment is merely an example, and the present invention is not limited to the illustrated arrangement. For example, the strength test specimens 10, the unconfined test specimens 20, and the confined test specimens 30 may all be arranged along a surface of the bottom portion 3b.
Alternatively, for example, the unconfined test specimens 20 and the confined test
25 specimens 30 may be arranged along a vertical direction.

[0125]

In the first embodiment described above, the strength test specimens 10, the unconfined test specimens 20, and the confined test specimens 30 are placed in the same storage container 3, and their physical properties are measured. This is intended to achieve the same temperature history by storing a plurality of test specimens, including the strength test specimens 10, the unconfined test specimens 20, and the confined test specimens 30, in the same heat-insulated storage container 3, so that a temperature in the container rises due to heat generated by hydration reactions occurring in these test specimens and then decreases as progress of the hydration reactions converges.

10 [0126]

In other words, the test specimens (the strength test specimens 10, the unconfined test specimens 20, and the confined test specimens 30) do not necessarily need to be placed in the same storage container 3, as long as they can be placed in heat-insulated storage containers under the same temperature history. For example, the reduction coefficient for the Young's modulus of the concrete may be derived by the method in the first embodiment while the respective test specimens are stored in constant-temperature chambers programmed to generate a predetermined temperature history. Furthermore, in this case, physical properties of the concrete other than the reduction coefficient for the Young's modulus may also be derived in accordance with the method described above in the first embodiment.

20

[0127]

[Other Embodiments]

Hereinafter, other embodiments will be described.

[0128]

25 <1> In the above embodiments, at each arrival of a predetermined material-age

timing, the lid portion 2 is opened and the strength test specimen 10 is removed upward. However, a direction in which the strength test specimen 10 is removed is not limited to an upward direction. For example, a position of the lid portion 2 may be set to a lateral side, and the strength test specimen 10 may be removed from the lateral side.

5 **[0129]**

 <2> In the storage container 3, more strength test specimens 10 than a number of specimens to be removed at each material age and subjected to the above-described tests may be placed. These extra strength test specimens 10 are used to induce hydration reactions in the storage container 3 and thereby raise a temperature in the storage
10 container 3.

[0130]

 <3> If a plurality of confined test specimens 30 are placed in the storage container 3, confined stresses of the respective confined test specimens 30 may be derived based on measurement values from second strain sensors 35 disposed in the
15 confined test specimens 30, and an average value of the derived confined stresses may be used as a confined stress F.

[0131]

 Furthermore, in the above configuration, steel member ratios of confining steel members 34 disposed in the confined test specimens 30 may be made different from one
20 another. In this case, the confined stress F is derived based on a measurement value from the second strain sensor 35 disposed in each confined test specimen 30 and a steel member ratio of the confining steel member 34 disposed in the corresponding confined test specimen 30. An average value of confined stresses thus derived for the respective confined test specimens 30 may be used as the confined stress F.

25 **[0132]**

<4> Only one unconfined test specimen 20 may be placed in the storage container 3. Similarly, only one confined test specimen 30 may be placed in the storage container 3.

[0133]

5 <5> The present invention is not limited to the embodiments described above, and various modifications are included. For example, the above embodiments have been described in detail for a better understanding of the present invention, and are not necessarily limited to those having all of the configurations described. A scope of the present invention is indicated by the scope of claims, and it is intended that all
10 modifications within a meaning and scope equivalent to the scope of claims are included.

[Reference Signs List]

[0134]

15 1: evaluation device, 2: lid portion, 3: storage container, 3a: side portion of storage container, 3b: bottom portion of storage container, 6: filler, 10: strength test specimen, 11: tubular body, 12: internal space, 20: unconfined test specimen, 21: frame body, 23: internal space, 25: first strain sensor, 27: signal wire, 30: confined test specimen, 31: side plate, 32: end plate, 33: internal space, 34: confining steel member,
20 35: second strain sensor, 36: thermometer, 37: signal wire

[CLAIMS]

[Claim 1]

An evaluation device for evaluating properties of concrete to be measured, the
5 evaluation device comprising:

a strength test unit including a plurality of first cylindrical molds, each
configured to receive cast concrete;

an unconfined test unit including a first rectangular frame having a bottom and
configured to receive cast concrete;

10 a confined test unit including a second rectangular frame having a bottom and
configured to receive cast concrete, both ends of the second rectangular frame in a
longitudinal direction being restrained by a confining steel member having a thermal
expansion coefficient of less than $1 \times 10^{-6}/^{\circ}\text{C}$;

a heat-insulated storage container covering the strength test unit, the
15 unconfined test unit, and the confined test unit; and

a thermometer configured to measure a temperature change inside the storage
container,

wherein the unconfined test unit has a first strain sensor disposed within the
first rectangular frame, and

20 the confined test unit has a second strain sensor disposed on the confining steel
member.

[Claim 2]

The evaluation device according to claim 1,

25 wherein the storage container is made of a heat-insulating material and has a

removable lid portion, and

the strength test unit is positioned closer to the lid portion than the unconfined test unit and the confined test unit.

5 [Claim 3]

The evaluation device according to claim 2,

wherein the storage container has a bottom portion positioned opposite the lid portion, and side portions that cover the bottom portion from four directions,

the unconfined test unit and the confined test unit are arranged in a direction

10 along the bottom portion, and

a plurality of first cylindrical molds included in the strength test unit are arranged in a direction along the bottom portion in a state of being placed directly over the first rectangular frame included in the unconfined test unit and the second rectangular frame included in the confined test unit.

15

[Claim 4]

The evaluation device according to claim 1 or 2,

wherein the strength test unit includes the first cylindrical molds in a number equal to or greater than twice the number of types of target material ages in a strength
20 test of the concrete.

[Claim 5]

The evaluation device according to claim 1 or 2,

further comprising a heat-insulating filler that fills spaces between the plurality
25 of first cylindrical molds.

[Claim 6]

The evaluation device according to claim 1 or 2,
wherein the thermometer is attached to the unconfined test unit.

5

[Claim 7]

A method for evaluating properties of concrete using the evaluation device
according to claim 1, the method comprising:

a step (a) of placing, into the storage container, an unconfined test specimen
10 obtained by casting the concrete into the first rectangular frame, a confined test
specimen obtained by casting the concrete into the second rectangular frame, and a
plurality of strength test specimens obtained by casting the concrete into the plurality of
first cylindrical molds;

a step (b) of, each time a predetermined material-age timing is reached,
15 removing a target material-age strength test specimen belonging to the plurality of
strength test specimens from the storage container, executing a Young's modulus
measurement test on the target material-age strength test specimen, and calculating a
pattern of change over time in a Young's modulus of the concrete;

a step (c) of calculating a pattern of change over time in a confined strain value
20 of the concrete, based on a first strain value that is a measurement value from the first
strain sensor of the unconfined test unit in a state of being placed in the storage
container, and a second strain value that is a measurement value from the second strain
sensor of the confined test unit in a state of being placed in the storage container;

a step (d) of calculating a pattern of change over time in a confined stress of the
25 concrete, based on a steel member ratio that is a ratio of the confining steel member in

the confined test specimen, a Young's modulus of the confining steel member, and the second strain value;

a step (e) of calculating an apparent Young's modulus during each of temperature rise and temperature drop, based on a correlation between the confined strain value and the confined stress; and

a step (f) of deriving a reduction coefficient for the Young's modulus during each of temperature rise and temperature drop, based on a ratio of the Young's modulus obtained in the step (b) and the apparent Young's modulus obtained in the step (e).

10 [Claim 8]

The method for evaluating properties of concrete according to claim 7, further comprising:

a step (g) of calculating an effective material age of the target material-age strength test specimen at the material-age timing, based on a temperature history in the storage container measured by the thermometer; and

a step (h) of obtaining a relationship between a material age of the concrete corresponding to the material-age timing and the effective material age obtained in the step (g).

20 [Claim 9]

The method for evaluating properties of concrete according to claim 8, further comprising:

a step (i) of executing a compressive strength test on the target material-age strength test specimen to obtain a pattern of change over time in compressive strength of the concrete; and

a step (j) of obtaining a relationship between the effective material age and the compressive strength of the concrete based on results of the step (h) and the step (i).

[Claim 10]

5 The method for evaluating properties of concrete according to claim 9, further comprising:

a step (k) of obtaining a relationship between the compressive strength and the Young's modulus of the concrete based on results of the step (b) and the step (i).

10 [Claim 11]

The method for evaluating properties of concrete according to claim 9, further comprising:

a step (l) of executing a splitting tensile strength test on the target material-age strength test specimen to obtain a pattern of change over time in splitting tensile

15 strength of the concrete; and

a step (m) of obtaining a relationship between the compressive strength and the splitting tensile strength of the concrete based on results of the step (i) and the step (l).

[Claim 12]

20 The method for evaluating properties of concrete according to claim 8, further comprising:

a step (n) of, after a lapse of 25 days or more since the step (a), removing the unconfined test specimen from the storage container, applying a temperature change to the unconfined test specimen in an adiabatic environment, and obtaining a thermal

25 expansion coefficient of the concrete from a relationship between temperature and a

measurement value from the first strain sensor;

a step (o) of calculating a pattern of change over time in an autogenous shrinkage strain of the concrete, based on a pattern of change in thermal strain obtained by multiplying a pattern of change over time in temperature measured by the

5 thermometer by the thermal expansion coefficient, and on a pattern of change in the first strain value obtained in the step (c); and

a step (p) of obtaining a relationship between the effective material age and the autogenous shrinkage strain of the concrete based on results of the step (g) and the step (o).

10

[Claim 13]

The method for evaluating properties of concrete according to claim 7,

wherein the thermometer is attached to at least one of the unconfined test unit and the confined test unit, and

15

the method further comprises a step (q) of performing inverse analysis on a relationship between the material age of the concrete and the measurement value from the thermometer, and obtaining an adiabatic temperature rise property of the concrete.

[Claim 14]

20

The method for evaluating properties of concrete according to claim 7,

wherein the storage container is made of a heat-insulating material and has a removable lid portion,

the strength test unit is positioned closer to the lid portion than the unconfined test unit and the confined test unit, and

25

the step (b) includes a step of, each time the material-age timing is reached,

opening the lid portion, removing the target material-age strength test specimen from the storage container, and placing, in the storage container, a heat-insulating filler in an amount corresponding to a region that was occupied by the removed target material-age strength test specimen.