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RILEM TC 176-IDC INTERNAL DAMAGE OF CONCRETE DUE TO FROST ACTION

Recommendations of RILEM TC 176-IDC: Test methods of frost resistance of concrete

The tests presented hereafter are drafts for general consideration. Comments should be sent to the TC Chairman: M. J. Setzer, University of Essen, IBPM - Institute of Building Physics and Material Science, Postfach 45117 Essen, Germany; email:mj.setzer@uni-essen.de, by 30 April 2002.
Remarks by the Chairman of RILEM TC 176-IDC:
I. Formal decisions:
The RILEM TC 176-IDC decided at its meetings in Bergamo (2000), Paris (2000) and Essen (2001):
1. Two test procedures shall be published as RILEM Recommendations:
CIF-test and modified Slab test.
The CIF test extends the existing RILEM Recommendation CDF test[1] which was developed for measuring the scaling under the attack of frost and de-icing agents.
The modified Slab test relies on the Swedish Standard SS137244.
2. The tests are presented to give a basis for gaining experience.
3. The descriptions shall be based on proposals already distributed to the Committee.
4. Responsible authors are for CIF-Test M. J. Setzer and for Slab-Test Per-Erik Petersson and Luping Tang.
5. Two inter-laboratory-tests have been performed by RILEM TC 176-IDC in 2000 – one for CIF and one for modified Slab test, each comprising three concretes. The results have been evaluated strictly basing on ISO 5725 by Dr. Auberg and Mrs. Kasparek for CIF and by Dr. Luping Tang for modified Slab test. The results have been cross-checked by the two groups. The RILEM TC 176-IDC decided to use these precision data for the drafts.
II. Comments by the Chairman:
1. It must be taken into account that the results and especially the level of damage is different in both tests. Therefore, it is not appropriate to compare the simple number even if similar physical parameters are used such as transit time, dynamic elastic modulus and relative length change. Based on the inter-laboratory test, the measured damage can be up to a factor of 3 higher in CIF than in modified Slab test.
2. The damage levels given in the precision tables are not to be mistaken as acceptance criteria. The RILEM TC 176-IDC is not prepared at this time to propose acceptance criteria. Acceptance criteria are in the responsibility of contractors committees of standardization. For this, additional data which link the test results with performance under practical conditions are necessary (such conditions can vary considerably based on local and regional climatic conditions).

CIF-Test - Capillary suction, Internal damage and Freeze thaw Test
Reference method and alternative methods A and B

Prepared by M. J. Setzer

Editorial Committee: R. Auberg, S. Kasparek, S. Palecki and P. Heine

1. SCOPE

Adequate resistance of concrete to freeze-thaw attack should be verified by laboratory tests such as the CIF Test. CIF means "Capillary suction, Internal damage and Freeze-thaw test". The CIF test is based upon the RILEM Recommendation of the CDF-test (*Capillary suction, Deicing agent and Freeze thaw Test*), where precision data for scaling have been determined, and complements this test.

During the CIF test, the degree of saturation of a concrete specimen is increased reproducibly with a defined test liquid, normally **demineralized water**, first by isothermal capillary suction and then by repetition of a well-defined freeze thaw cycle with uniaxial heat and liquid flux. This process enables the measurement of the damage to the internal structure of concrete after a number of freeze-thaw cycles or a specified degree of saturation has

(1) CDF Test - Test method for the freeze-thaw resistance of concrete - tests with sodium chloride solution (CDF). RILEM Recommendation TC117-FDC: Freeze-thaw and de-icing resistance of concrete. *Mater. Struct.* **29** (1996) 523-528.

been reached. When combined with a determination of surface scaling, it is possible to investigate the external as well as the internal damage of a specimen. The water uptake and associated degree of water saturation is a substantial parameter of the measurement and should be a required measurement for test result interpretation.

A **3% sodium chloride** solution is commonly employed to test freeze-thaw and de-icing agent resistance, as described in the CDF-test application form. With the CIF Test, a combination of both test procedures is possible. While using 3% NaCl the surface scaling becomes dominant and the internal damage has to be considered as an additional parameter.

The procedure can be applied to test all types of concretes (cast-in-place concrete, production items such as paving blocks and curbs, and precast members), as well as concrete mix constituents and individual concrete mixtures. The test requires specimens, which are essentially homogeneous. Multilayered specimens or severely segregated concretes need special expert investigation.

2. STANDARDS

prEN-ISO 2736/2: Testing hardened concrete-test specimens. Part 2: Making and curing of test specimens.

E ISO/DIS 8047 (1982-12): Concrete, hardened; determination of ultrasonic pulse velocity, (Festbeton; Bestimmung der Ultraschall-Ausbreitgeschwindigkeit)

ISO 5725/1 to 6-1990: Accuracy (trueness and precision) of measurement methods and results.

VDI/VDE 3522: Time performance of contact thermometers (Zeitverhalten von Berührungsthermometern). June 1987.

3. DEFINITIONS

1. The *freeze-thaw resistance* is the resistance against alternating freezing and thawing in the presence of demineralized water as the test liquid.

2. The *freeze-thaw and de-icing agent resistance* is the resistance against alternating freezing and thawing in the presence of a de-icing agent solution as the test liquid.

3. The *test liquid* is the liquid which is taken up during the test procedure (demineralized water or de-icing agent solution).

4. *Scaling* is the loss of material at the surface of concrete due to freeze-thaw or freeze-thaw de-icing agent attack.

5. *Internal damage* is the deterioration of the internal structure of concrete (even without visible external damage) which leads to a change in the concrete properties (*e.g.* a reduction of the dynamic modulus of elasticity).

6. The *reference point* is the physical measuring point at which the temperature cycle is controlled.

7. The *reference temperature* is the temperature measured at the reference point.

8. The *test surface* is the surface of the test specimens over which the temperature change and test liquid attack the specimens during the test procedure.

9. The *ultrasonic transit path* is the length over which the ultrasonic transit time is measured.

10. The *transit time* is the time required by an ultrasonic pulse to cover the ultrasonic transit path between the transmitter and receiver for ultrasonic waves.

11. The *ultrasonic transit axis* is the hypothetical shortest distance between the centres of the coupling surfaces of the transmitter and receiver transducers.

12. *Coupling medium*. The test liquid is used as the coupling medium. It enables a reproducible signal transfer between the transducers and the specimen.

13. *Measurement intervals* are the time intervals after which deterioration is determined.

Measurements should be made at 0 cycles and at most every 14 cycles. Every 4 – 6 cycles is the preferred interval.

14. *Test duration*. Depending upon the used test liquid:

I) demineralized water: **56** freeze-thaw cycles

II) de-icing agent solution: **28** freeze-thaw cycles.

4. EQUIPMENT

1. *Climate chamber* with a temperature of 20 ± 2°C and a relative humidity of 65 ± 5%.

2. Evaporation is measured using an *evaporation bowl* with a depth of approximately 40 mm and a cross-sectional area of 225 ± 25 cm^2.

3. *Lateral sealing* by epoxy resin or aluminium foil with butyl rubber. Both must be durable at temperatures of -20°C. They must not be brittle at the minimum temperature reached.

4. *Test liquid*:

I) demineralized water

II) de-icing agent solution *e.g.*, 97% by weight of demineralized or distilled water and 3% by weight of NaCl.

5. *Test containers* (Figs. 1 and 2): The test containers consist of stainless steel. The thickness of the air layer between the vertical side of the specimen and the test container is restricted to 30 ± 20 mm.[2,3] A spacer of 5 ± 0.1 mm and a lid is required.

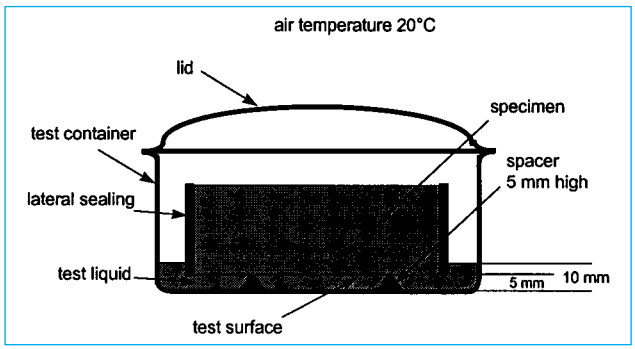

Fig. 1 – Capillary suction.

(2) The air layer between the vertical side of the specimen and the test container acts as thermal insulation.

(3) The stainless steel containers should completely fill the temperature controlled chest. Different specimen sizes can be accommodated by a series of modular containers meeting the vertical air layer thickness requirement.

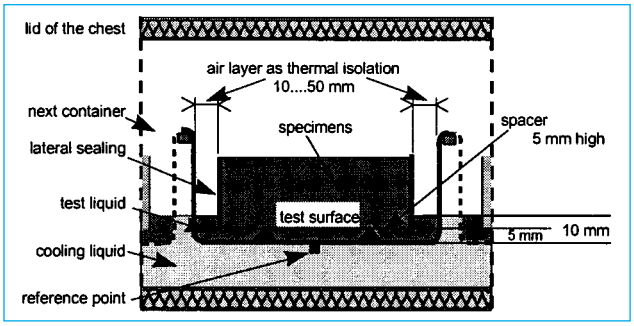

Fig. 2 – Test container with specimen in the liquid cooling bath.

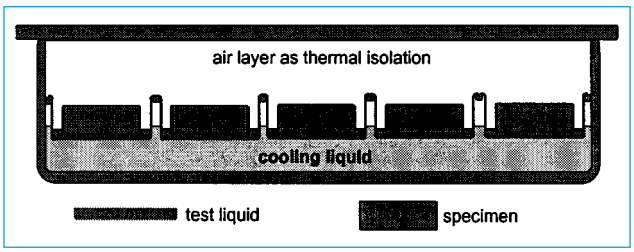

Fig. 3 –Temperature controlled chest.

6. *Temperature controlled chest* (Fig. 3). A chest with a liquid cooling bath is used. The temperature of the cooling bath should be controlled by an appropriate device. The heating and cooling capacity and the control unit must be capable of maintaining the temperature regime at the reference point as defined in 6.1. "*Temperature cycle*".

The chest must be equipped with supports for the test containers above the cooling bath to ensure an immersion depth of the bottom of the test containers of approximately 15 mm. During the freeze-thaw cycles the upper space of the chest containing the specimens must be separated from the cooling bath either by the test containers or by other lids.[4]

A test container placed at an appropriate position in the bath (usually in the centre) is used to monitor and control the reference temperature.

The reference temperature is measured in the coolant at the bottom of a test container. The reference point is positioned in good thermal contact at the centre of the container base.

A temperature gauge with an accuracy of ± 0.05K at 0°C is recommended for the measurement. The temperature gauge should be in the form of a rectangular container with dimensions 50 × 6 × 6 mm ± 0.2 mm. The temperature gauge should be fixed so that the long side lies in the direction of flow. The time constant (t-90%) of the probe (without securing device), determined according to VDI/VDE 3522 in a flowing water bath, should be 6.3 s ± 0.8 s. The minimum temperature of -20°C should be used for calibration.

6.1 *Temperature cycle*. A 12 h freeze-thaw cycle is applied (Fig. 4). Starting at +20°C the temperature is

(4) When conducting the test in a cryogenic bath, no cover of the test containers is required, since the chest lid will provide a sufficient evaporation barrier, while the container wall will serve as a cold trap.

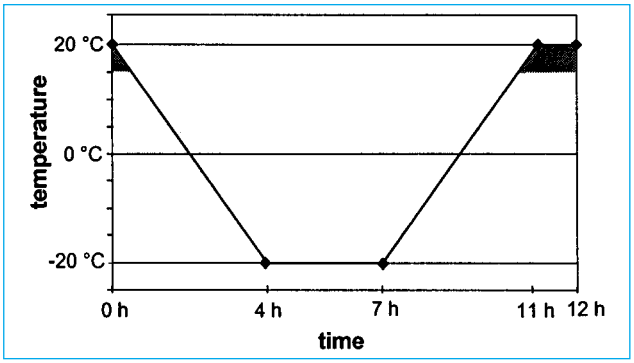

Fig. 4 – Control temperature cycle.

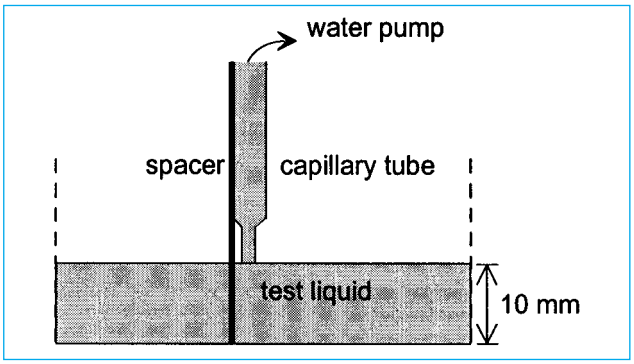

Fig. 5 – Suction device to remove the liquid exceeding the level of 10 mm in the test containers.

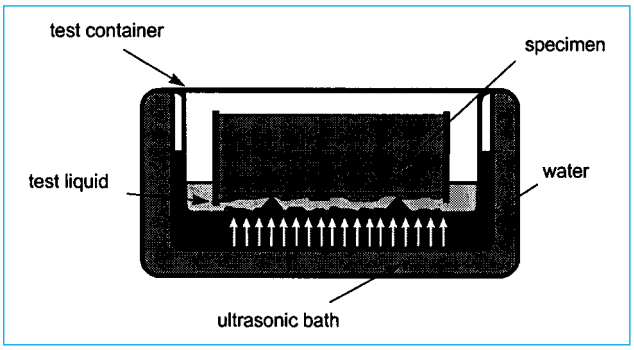

Fig. 6 – Ultrasonic bath.

lowered in 4 h with a constant cooling rate of 10 K/h. It is kept constant for 3 h at -20°C and increased in 4 h with a constant heating rate of 10 K/h. It is kept constant for 1 h at +20°C. The temperature cycle is monitored at the reference point. The deviation of temperature measured at the reference point should not be more than ± 0.5 K at least at the minimum temperature and more than ± 1 K at other temperatures. A constant time shift between the test containers is acceptable. The damage parameters may be measured while temperature is above 15°C (shaded area in Fig. 4).

7. *Unit for adjusting liquid level, e.g.*, by a suction device (Fig. 5). The suction device may consist of a capillary tube with a spacer of 10 ± 1 mm that is connected with a water jet pump to suck up the excessive liquid in the test containers.

8. *Ultrasonic bath* (Fig. 6). The size of the ultrasonic bath must be sufficiently large. The test containers have

to fit in the ultrasonic bath without mechanical contact. Additionally, a minimum distance between the test container and the bottom of the bath of 15 mm must be ensured. The bath should provide the following power data: ERS power 250 W; HF peak power 450 W under double half-wave operation; frequency 35 kHz.

9. *Equipment for measuring the ultrasonic transit time*. The transit time is measured using conventional commercially available ultrasonic equipment, which is suitable for determining the transit times of longitudinal waves in porous building materials according to E DIN ISO 8047. The transducers should operate in frequency range between 50 and 150 kHz.

10. *Test container for ultrasonic transit time measurement*. A rectangular container (*e.g.* PMMA) is used for the transit time measurement. The transducers are mounted in recesses in two opposite faces of the container so that the transit axis lies parallel to and at a distance of 35 mm from the test surface (Fig. 8).

11. *Particle collector*. A plate (1 mm stainless steel) with handles collects the scaled particles of the specimens during measurement of liquid uptake and internal damage. The dimensions of the particle collector must be sufficiently larger than the test surface of the specimen to ensure that all scaled material can be collected. The edges of the plate must not be raised by more than 10 mm.

12. *Drying cabinet* for a temperature of (110 ± 5)°C.

13. *Paper filter* for collecting scaled material.

14. *Balance* with an accuracy of at least ± 0.01 g.

15. *Balance* with an accuracy of at least ± 0.1 g.

16. *Vernier callipers*, with an accuracy of at least ± 0.1 mm.

5. TEST SPECIMENS

5.1 Requirements on size and quantity of specimens

For one series a number ≥ 5 specimens[5] is recommended and the total test surface area should be ≥ 0.08 m^2 (all samples taken together) if scaling is measured. The recommended height of the specimens is 70 mm ± 5mm. The smallest dimension of the test surface should not be less than 90 mm, and irregularly-shaped specimens should be large enough to fit a 90-mm diameter circle on the test surface. The length/height ratio should not be above three.

In general, the length of the specimen should be longer than the ultrasonic wavelength used and the smallest dimension of the specimen should be many times longer than the maximum aggregate size used.[6]

5.2 Making test specimens for testing concrete mixes or concrete constituents in a mix (reference specimens)

For testing concrete mixes or concrete constituents in a mix, the test specimens are cast and compacted on a vibrating table in 150 mm cube moulds according to prEN-ISO 2736/2. Centred in the mould is a vertical PTFE plate, which separates the mould into two halves. The PTFE plate must not be treated with any demoulding agent. The concrete surface at the PTFE plate is the test surface. For a larger aggregate size the PTFE disk can be placed at one side.

As an alternative, it is permissible to insert two PTFE disks at two opposite vertical sides. The concrete surfaces adjacent to the PTFE disks are the test surfaces. After storage under water, the specimens are cut through the centre between the two test surfaces.

After 24 ± 2 hours of curing the specimens are removed from the mould and stored for 6 days (until the age of 7 days) in tap water at 20 ± 2°C. (If strength development of the specimens is low, the curing duration in the mould can be increased. The storage time in tap water is then decreased by the same amount.).

After storage under water, the specimens are cut at the rough lateral side to a length of 110 mm. The rough lateral side was the upper side of the cube during the making. The reference specimen has the dimension of 110 x 150 x 70 mm (± 2 mm).

5.3 Test specimens for testing the surface of concrete structures

The test surface should correspond to the surface of the real structure exposed to weathering. The test surface should be plane and can be of any kind - cast, screeded, sawed or of different texture.

The specimens should comply with the description of the specimens in section 5.1.

5.4 Test specimens for testing precast concrete elements

Small precast concrete elements, such as concrete blocks and flags, can be tested directly, independent of their form. If the dimension exceeds 250 mm, the element should be cut. The test surface is the weathered surface of the element and should be plane.

The specimens should comply with the description of the specimens in section 5.1.

6. TEST PROCEDURE

The test procedure consists of three steps: the dry storage, the pre-saturation by capillary suction and the freeze-thaw cycles. The test procedure starts immedi-

(5) A minimum number of 5 specimens is recommended for statistical evaluation and for finding possible outliers.

(6) At 50 kHz the wavelength is approximately 90 mm in undamaged concrete (see DIN ISO 8047 and also AUBERG, R.: Reliable testing of freeze-thaw and de-icing salt resistance, University of Essen 1998 PhD thesis).

ately after the curing period. This is at an age of 7 days in the case of test specimens made following section 5.2.

6.1 Dry storage

The concrete specimens are stored in the climate chamber (20°C/65% RH) for surface drying for 21 days. The specimens are to be placed on their sides and at least 50 mm apart so that the test surfaces are free of obstruction. Monitoring of each specimen's mass is recommended.

In the climate chamber the evaporation from a free water surface shall be 45 ± 15 g/m^{2}h. The evaporation is measured by mass loss of a water filled evaporation bowl with a depth of approximately 40 mm and a cross-sectional area of 225 ± 25 cm^2. The bowl shall be filled up to 10 ± 1 mm from the brim.

6.2 Pre-saturation

6.2.1 Preparation of specimens

Between 7 and 2 days before pre-saturation the specimens should be sealed on their lateral surfaces either with aluminium foil with butyl rubber or with a solvent free epoxy resin.[7] The specimens must be clean and dry. Before sealing the lateral surfaces, it is recommended that they be treated with an appropriate primer.

Before and after the specimens are sealed they have to be weighted with an accuracy of ± 0.1 g, in order to measure the reference mass of the samples without lateral sealing for the determination of the water uptake. (see section 7.3).

Sealing the lateral surfaces

One of the following two procedures should be used to seal the lateral surfaces of the specimens:

a) Sealing with aluminium foil and butyl rubber

A piece of aluminium foil with butyl rubber is glued tightly on the lateral surfaces with an overlap of 20 mm. The top surface of the specimen and the test surface must remain free of obstruction.

b) Sealing with epoxy resin

A solvent free epoxy resin is laid on the lateral surfaces, whereas the bottom of the specimens and the test surface must be kept free.

6.2.2 Presaturation of test liquid by capillary suction

Following dry storage the specimens are placed in the test containers on the 5 mm high spacers with the test surface on the bottom. Subsequently, the test liquid is added into the container to a height of 10 ± 1 mm without wetting the specimen's top. During the capillary suction the test container must be closed with the lid. The capillary suction period is 7 days at a temperature of 20 ± 2°C. During capillary suction the liquid level should be checked in regular intervals. The mass increases of the specimens should be measured.

6.3 Freeze-thaw testing

The freeze thaw test consists of
1. subjecting the specimens to a temperature cycle,
2. determining specimen deterioration.

6.3.1 Cleaning of test surface before starting the freeze-thaw cycles

Before starting the freeze-thaw cycles, loosely adhering particles and dirt should be removed from the test surfaces of the specimens by treatment in the ultrasonic bath as described in section 7.2 Determination of surface scaling a). The material removed is discarded.

7. MEASUREMENTS

7.1 Sequence of measurement of scaling, water uptake and internal damage

The following sequence of the measurement is imperative:
1. surface scaling,
2. water uptake as relevant information,
3. internal damage (ultrasonic transit time as the reference method or fundamental transverse frequencies or length change as alternative methods).

As a rule, water uptake is measured immediately after determining the scaled material.

If the measurement sequence is interrupted, the specimen must be positioned in the test container with the test liquid to prevent drying.

A collector of scaled material (Fig. 7) is necessary while measuring the other parameters. During the measurement of liquid uptake and of internal damage the individual specimens are placed on a steel plate to enable collection of scaled material loosened during testing. The material collected on the steel plate must be returned to the test container after the internal damage parameter

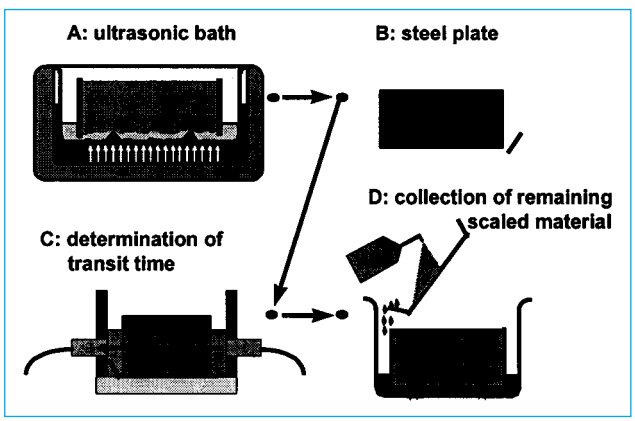

Fig. 7 – Specimen handling for the simultaneous determination of scaling and ultrasonic transit time (Reference method).

(7) When conducting frost/de-icing salt tests, this prevents misleading results due to possible scaling of the lateral surfaces.

measurement. This material must be taken into account in the next measurement of scaled material.

All following described test procedures should be carried out in accordance with the defined measurement intervals.

7.2 Determination of surface scaling

a. Procedure

The test container is dipped into the contact liquid of an ultrasonic bath and subjected to ultrasonic cleaning for 3 minutes, in order to remove loosely adhering scaled material from the test surface after n freeze-thaw cycles.

The solution containing the scaled material is filtered. The paper filter is subsequently dried at 110 ± 5°C for 24 h and cooled for 1 h (± 5 min) at 20 ± 2°C and 60 ± 5 R.H. The mass of the filter containing the dried scaled material μ_b is determined to 0.01 g precision. The mass of the empty filter μ_f is determined prior to filtering with the same precision.

The mass of the scaled material μ_s is then: $\mu_s = \mu_b - \mu_f$.

b. Evaluation of scaling

The total amount of scaled material m_n related to the test surface after the *n*th cycle is to be calculated for each measuring occasion and each specimen:

$$m_n = \frac{\sum \mu_s}{A} * 10^6 \quad g/m^2 \qquad (1)$$

μ_s is the mass of scaled material of the measurement after n cycles (g) with an accuracy of 0.01 g. The sum is taken over all measurements until the *n*th cycle.

A is the area of the test surface. It is calculated on the basis of the linear dimensions. They are taken as the average of at least two measurements determined to the nearest 0.5 mm.

The mean value and the standard deviation of the scaled material should be determined. The result should be checked for outliers.

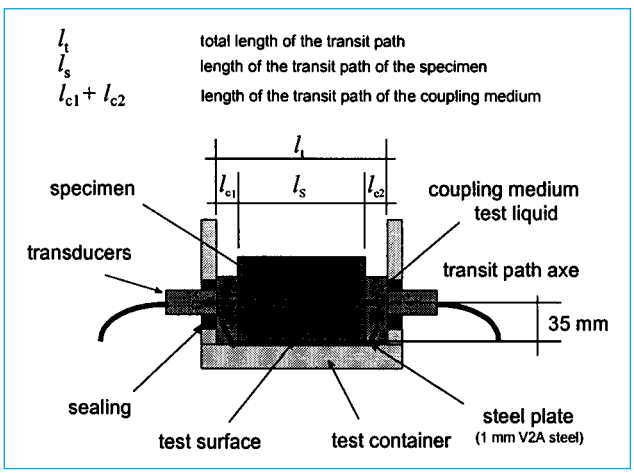

Fig. 8 – Test equipment for measuring the ultrasonic transit time

7.3 Measurement of water uptake

a. Procedure

After removing the scaled material from the test surface (see 7.2 Determination of surface scaling) the specimens are placed vertically on an absorbent surface (laboratory towel) to permit the run off of water from the test surface. The lateral and upper sides of the specimens have to be dried smoothly with a laboratory towel. In order to avoid loss of scaled material, the balance is zeroed with a steel plate on it, and the dried specimen is placed on the steel plate for weighing. The mass of each specimen is then measured with a precision of ± 0.1 g.

b. Evaluation of water uptake

The relative increase in mass of each specimen Δw_n after the nth cycle is calculated by:

$$\Delta w_n = \frac{w_n - w_1 + \sum \mu_n}{w_0} * 100 \quad wt - \% \qquad (2)$$

μ_n is the mass of total scaled material after n cycles (g) with an accuracy of 0.01 g. The sum is taken over all measurements until the *n*th cycle.

w_0 is the reference mass of the each specimen without sealing mass after pre-storage (g).

w_1 is the mass of each specimen including sealing mass before re-saturation starts (g).

w_n is the mass of each specimen after n cycles (g).

The mean value and the standard deviation of the mass increase should be determined. The result should be checked for outliers.

7.4 Internal damage - Reference method (ultrasonic transit time)

a. Procedure

As shown in Fig. 7, the steel plate with the specimen is placed in the test container. The ultrasonic transit axes marked on the specimens during the first measurement must be used for all subsequent investigations. For each specimen the transit time is measured along two perpendicular transit axes 35 mm from the test surface. In the case of rectangular specimens, the coupling point must be centered between the edges of the specimen. During the first measurement the final position is fixed by slightly shifting the specimen (maximum ± 10 mm) in such a way that a minimum transit time is reached. These points are marked for future measurements. Before capillary suction commences, the specimen length which is to be crossed by the ultrasonic waves is measured to an accuracy of ± 0.5 mm. The sealing material on the sides of the specimen is excluded from this length. Before commencing the freeze-thaw cycles, the transit time is determined to an accuracy of ± 0.1 µs. Prior to starting a series of measurements, the equipment must be calibrated.

The temperature of the coupling medium and specimens should be 20 ± 5°C when the transit time is being measured. The time period in which the test surface is in contact with air should be kept as short as possible. Moistening of the upper specimen surface must be avoided.

The coupling medium is the test liquid. The transducers are mounted in the sides of the rectangular container so that the transit path axis is parallel to the test surface and 35 mm from the test surface. The container is filled with the test liquid to a level of 10 mm above the transducers, but not above the top of the specimen. The upper surface of the specimens must be kept dry. The total thickness of the coupling medium should be approximately 10 mm (5 mm on both sides of each specimen).

The actual path of the ultrasonic waves l_c in the coupling medium must be determined to an accuracy of ± 0.5 mm.

During testing, care should be taken that air bubbles do not adhere to the transducers and the sides of the specimens. The sealing material should be securely attached to the sides of the specimens.

b. Evaluation of the internal damage

The transit time in the coupling medium t_c is calculated from the path length in the coupling medium l_c and the velocity of the ultrasonic signal in the coupling medium v_c:

$$t_c = \frac{l_c}{v_c} \text{ ms} \qquad (3)$$

with

l_c path length in the coupling medium [mm]

v_c velocity of the ultrasonic signal in the coupling medium which can be assumed for water between 20°C ± 5°C to 1440 m/s

t_c Transit time in coupling medium [ms]

The change of relative transit time τ_n after n freeze-thaw cycles is calculated separately for each specimen and transit axis by[8]:

$$\tau_n = \frac{t_{cs} - t_c}{t_n - t_c} \qquad (4)$$

The symbols are as follows:

τ_n Relative transit time

n Number of freeze-thaw cycles

t_{cs} Total transit time after capillary suction (cs) [ms]

t_n Total transit time after n freeze-thaw cycles (ftc) [ms].

Instead of change of relative transit time it is convenient to express internal damage as change of dynamic modulus of elasticity of ultrasonic transit time $R_{u,n}$. In this test procedure its relative change after n freeze-thaw cycles is calculated by the relation[9]:

$$R_{u,n} = \tau_n^2 \qquad (5)$$

The average over the values for both transit axes gives the change in the relative dynamic modulus of elasticity for the specimen.

The mean and standard deviation of the relative dynamic modulus of elasticity over a test series must be determined. The results should be checked for outliers.

(8) The change in transit length can be neglected.

(9) For this equation changes of density, size of specimen and Poisson's ratio are neglected. This is not a serious restriction since the detection of damage is the aim of the test and ultrasonic transit time is the relevant parameter. The dynamic modulus of elasticity is only a quantity which is a better known common engineering quantity.

8. PRECISION DATA OF CIF TEST FOR CONCRETE MIXTURES

8.1 General

Three different precision variables are distinguished: repeatability, reproducibility and scattering of laboratories with respect to each other. Using ISO 5725 as a guide, the precision data of the CIF test with demineralized water as the test liquid was found for various concrete mixtures according to 5.1 "Requirements on size and quantity of specimens" and made according to section 5.2 "Making test specimens for testing concrete mixes or concrete constituents in a mix (reference specimens)".

8.2 Measurement of Internal damage – reference method (ultrasonic transit time)

8.2.1 Relative dynamic modulus

The precision data for the relative dynamic modulus are given in Table 1. These data apply for laboratory concrete series which are measured according to section 7.4.

Table 1 – Precision data according to ISO 5725 expressed as relative dynamic modulus. Measurement of internal damage - Reference method

damage to concrete	slight	medium to extensive	extensive to total
relative dynamic modulus of elasticity with respect to initial value	> 90%	90% - 60%	< 60%
	standard deviations		
precision of repeatability s_r (includes scatter due to operator, material and ultrasonic test)	< 2.2%	< 5.2%	< 5.6%
precision of reproducibility s_R	< 3.7%	< 7.6%	< 8.0%

The precision data can be expressed as:

$$s_r = -0.1602\, R_{u,n}^2 + 0.1422\, R_{u,n} + 0.0242 \quad (R_{u,n} \text{ 0.25 to 1.0 with } R^2 = 0.65) \qquad (6)$$

$$s_R = -0.2265\, R_{u,n}^2 + 0.2088\, R_{u,n} + 0.0321 \quad (R_{u,n} \text{ 0.25 to 1.0 with } R^2 = 0.56) \qquad (7)$$

where s_r and s_R denote the standard deviation of repeatability and reproducibility and $R_{u,n}$ is relative dynamic modulus calculated with Equation (5).

REMARK: The precision data and the equations based on the results of the inter-laboratory-test of RILEM TC IDC with 9 institutes testing 3 different kinds of concrete series.

8.2.2 Relative transit time

The precision data for the relative transit time are given in Table 2. These data apply for laboratory concrete series which are measured according to section 7.4.

Table 2 – Precision data according to ISO 5725 expressed as relative transit time. Measurement of internal damage

damage to concrete	slight	medium to extensive	extensive to total
relative transit time with respect to initial value	> 95%	95% - 80%	80% - 60%
	standard deviations		
precision of repeatability s_r (includes scatter due to operator, material and ultrasonic test)	< 1.4%	< 3.0%	< 5.1%
precision of reproducibility s_R	< 1.7%	< 4.1%	< 7.2%

The precision data can be expressed as:

$s_r = -0.1078\ \tau_n + 0.116$ (τ_n 0.5 to 1.0 with $R^2 = 0.76$) (8)

$s_R = -0.1553\ \tau_n + 0.1648$ (τ_n 0.5 to 1.0 with $R^2 = 0.78$) (9)

where s_r and s_R denote the standard deviation of repeatability and reproducibility and τ_n is relative transit time calculated with Equation (4).

REMARK: The precision data and the equations based on the results of the inter-laboratory-test of RILEM TC IDC with 9 institutes testing 3 different kinds of concrete series.

8.3 Measurement of Internal damage – alternative method (resonance frequency)

The precision data for the resonance frequency can be given as equations. These data apply for laboratory concrete series which are measured according to the Annex, Alternative method A.

The precision data can be expressed as:

$s_r = -0.1799\ R_{f,n}^2 + 0.1832\ R_{f,n} + 0.0019$
(R_f 0.25 to 1.0 with $R^2 = 0.70$) (10)

$s_R = -0.3384\ R_{f,n}^2 + 0.333\ R_{f,n} + 0.0075$
(R_f 0.25 to 1.0 with $R^2 = 0.63$) (11)

where s_r and s_R denote the standard deviation of repeatability and reproducibility.

REMARK: The equations based on the results of the inter-laboratory-test of RILEM TC IDC with 4 institutes testing 3 different kinds of concrete series.

8.4 Measurement of water uptake

The precision data for the water uptake are given in Table 3. These data apply for laboratory concrete series which are measured according to section 7.3.

Table 3 – Precision data according to ISO 5725. Measurement of water uptake

Water uptake	0 to 0.5 wt-%	0.5 to 1.5 wt-%	> 1.5 wt-%
	standard deviations		
precision of repeatability s_r	0.014 wt-%	0.027 wt-%	0.054 wt-%
precision of reproducibility s_R	0.029 wt-%	0.058 wt-%	0.115 wt-%

The precision data can be expressed as:

$s_r = 0.0265\ \Delta w_n + 0.0005$
(Δw_n 0 to 2.5 with $R^2 = 0.30$) or 0.09 wt% as total (12)

$s_R = 0.0569\ \Delta w_n + 0.0008$
(Δw_n 0 to 2.5 with $R^2 = 0.30$) or 0.17 wt% as total (13)

where s_r and s_R denote the standard deviation of repeatability and reproducibility and Δw_n is water uptake during freeze thaw test (2).

REMARK: The precision data and the equations based on the results of the inter-laboratory-test of RILEM TC IDC with 9 institutes testing 3 different kinds of concrete series.

8.5 Measurement of scaling

The precision data apply for laboratory concrete series which are measured according to section 7.2.

The precision data for surface scaling are only available in the range of scaling between 0 and 500 g/m^2.

$s_{r500} = 120$ g/m^2 (CoV 24%)

$s_{R500} = 160$ g/m^2 (CoV 32%).

The precision data for surface scaling will be completed at a later date.

8.6 Measurement of Length Change

Precision data for the length change are not available.

9. REPORT

The test report shall contain at least the following information:

1. A reference to this description.
2. Measures, mass, origin and marking of the specimens.
3. If concrete mixes or constituents are tested, the composition of the concrete.
4. The composition of the test liquid.
5. The change in calculated relative dynamic modulus of elasticity for each specimen as well as the mean value and standard deviation in % rounded to the nearest 1%, along with the number of freeze-thaw cycles carried out. This should be reported for at least the total number of freeze-thaw cycles carried out.
6. The amount of scaled material for each specimen as well as the mean value and the standard deviation in g/m^2 rounded to the nearest 1 g/m^2 after termination of the test.
7. The number of freeze-thaw cycles carried out.
8. The mass of solution sucked up during the capillary suction period for each specimen as well as the mean value and the standard deviation.

9. Visual assessment (cracks, scaling from aggregate particles) before the start and at least at the end of the test.

10. Any deviations from the standard test procedure.

11. Total length of the period of pre-storage, exclusive of the conditioning period, up to each length measurement after n freeze thaw cycles and the end of the test.

12. Length change data, reported as percent increase or decrease in linear dimension to the nearest 0.001 %, based on the initial measurement made at the end of the conditioning period.

(The reference method is published in: Setzer, M. J. and Auberg, R., (1998) CIF-Test - Method for Testing the Resistance of Concrete against frost. *Concr. Precast. Plant* **4** 94-106).

Annex- alternative methods A and B

ALTERNATIVE METHOD A - MEASUREMENT OF FUNDAMENTAL TRANSVERSE FREQUENCIES

a. General

Specimens having either very small or very large ratios of length to maximum transverse direction are frequently difficult to excite in the fundamental mode of vibration. Best results are obtained when this ratio is between 3 and 5.

The conditions of manufacture, the moisture content and other characteristics of the test specimens influence the results obtained.

Different computed values for the dynamic modulus of elasticity may result from widely different resonant frequencies of specimens of different sizes and shapes of the same concrete. Therefore, comparison of results from specimens of different sizes or shapes should be made with caution.

b. Standards

ASTM C 215-97 - Fundamental Transverse, Longitudinal, and Torsional Frequencies of Concrete Specimens (partly adopted and modified).

c. Definitions

Fundamental transverse frequency is the first frequency at which a specimen vibrates in transverse bending. At the fundamental transverse frequency there are two nodal points located approximately 22.4 percent of the specimen length from the ends of the specimen.

d. Equipment

1. Fourier Analyzer - Equipment capable of FFT analysis of vibrational input data should be used to convert time-domain measurements to frequency-domain response. The equipment should be capable of averaging multiple frequency response measurements from a single specimen prior to determination of fundamental frequency. The equipment should have at least two input channels, and should be able to use the signal from one channel to normalize the signal from a second channel. This allows multiple readings to be averaged even though the vibration responses may have been produced by different impact magnitudes. The equipment should also be able to use a minimal input level in one channel to trigger recording of data in all channels. The equipment should allow independent setting of the lower and upper limits of the frequency range in order to provide better resolution near the fundamental frequency. The equipment should have a maximum frequency capability of at least 1 kHz above the expected maximum fundamental frequency of the specimens being tested. A sensitivity of 0.1 to 1.0 AC volts for the excitation (hammer) channel and 0 to 5.0 AC volts for the vibration response channel (accelerometer) have been found to be appropriate for the hammer and accelerometer described below. The equipment should be capable of producing a visual display of the frequency response spectrum. This can be accomplished either directly by the equipment or through the use of a personal computer connected to the analyzer.

2. *Modally Tuned Impact Hammer* - The vibrations in the specimen being tested are produced by impact. The impact device should be capable of producing a flat frequency response over the entire frequency range being sampled. A modally tuned impact hammer with a mass of 140 g and a frequency response of 0-8 kHz has been found to produce the appropriate impact. The impact tip of the hammer should be of sufficient hardness and appropriate shape to neither be damaged by the specimen nor cause damage to the specimen when an impact of proper magnitude is produced. A spherical tip has not been found to be necessary. The hammer should be provided with an electronic load cell and appropriate power supply capable of producing an output voltage proportional to the magnitude of the impact with the specimen. The sensitivity of the load cell should be 10 to 15 mV/N.

3. *Accelerometer and Power Supply* - The vibration response of the specimen should be measured with an accelerometer having a flat base. The mass of the accelerometer should not exceed 3 g, and the upper range of its operating frequency should be at least 1 kHz above the maximum expected fundamental frequency. The fundamental frequency of the accelerometer should be at least twice the highest expected fundamental frequency of any of the specimens to be measured. The accelerometer should be provided with an appropriate power supply, and the output of the accelerometer/power supply combination should be at least 50 mV/g. Amplification of the accelerometer output may be necessary to achieve the proper output level.

4. *Specimen Support* - The support shall permit the specimen to vibrate without significant restriction. This

may be accomplished by supporting the specimen on knife-edges located near the nodal points or on a thick pad of sponge rubber. The support shall be so dimensioned that its fundamental frequency falls outside the frequency range of use. An example for the reference specimen size is given in Fig. 9.

e. Determination of transverse frequency

1. Place the specimen on the support (*e.g.* plastic frame), with the test face down, in such a manner that it may vibrate without significant restriction in a free transverse mode.

2. Attach the accelerometer to the top surface of the specimen, close to the end and midway between the corners. Either a rubber band (around the end of the specimen) or adhesive wax can be used to hold the accelerometer in place.

3. Lightly tap the centre of the top face of the specimen with the instrumented hammer. The tap should be strong enough to produce an output voltage of 0.5 to 1 V. The visual display of the frequency response curve measured by the accelerometer can be used to determine if the tap produced a "clean hit". Possible reasons for abnormal looking frequency response curves include not stopping the specimen vibration from a previous hit, and "double tapping" the specimen. A good tap should clearly indicate the fundamental transverse vibration[10] at the portion of the with the highest amplitude. If a good frequency response curve is produced from the tap, press the appropriate key on the equipment control panel to save the result.

f. Evaluation of the internal damage

In this procedure the relative dynamic modulus of elasticity after n freeze-thaw cycles is calculated separately for each specimen by[11] (This dynamic elastic modulus cannot be directly correlated with the dynamic elastic modulus found by ultrasonic transit time for non-homogenous, *i.e.*, with locally different degree of saturation or damaged specimens. In both cases it is supposed by the theoretical basis that the material is homogeneous.):

$$R_{f,n} = \left(\frac{f_n}{f_0}\right)^2 \cdot 100\% \qquad (I1)$$

The symbols are as follows:

$R_{f,n}$ relative dynamic modulus of elasticity
n Number of freeze-thaw cycles
f_n fundamental frequency after n freeze-thaw cycles
f_0 fundamental frequency after re-saturation, before freeze-thaw cycles.

(10) For fundamental transverse vibration, the nodal points are located 0.224 of the length of the specimen from each end (approximately the quarter points). Vibrations are a maximum at the ends approximately three fifths of the maximum at the centre, and zero at the nodal points. Therefore, movement of the pickup along the length of the specimen will inform the operator whether the vibrations observed are from the specimen vibrating in its fundamental transverse mode. For the reference specimen this means the nodal points are 0.224 x 150 mm = 33.6 mm from the specimen ends. (Fig. 9).

(11) A correlation between methods A and B has been found by Auberg - PhD thesis (6) -with $R_{f,n} = 1.47 * R_{u,n}$.

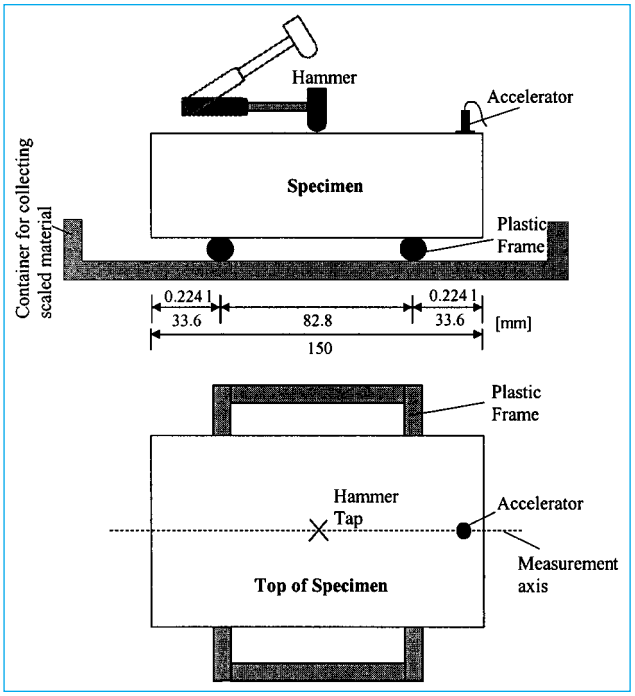

Fig. 9 – Test equipment for measuring the fundamental transverse frequencies (reference specimens).

The mean and standard deviation of the relative dynamic modulus of elasticity over a test series must be determined. The results should be checked for outliers.

ALTERNATIVE METHOD B - MEASUREMENT OF LENGTH CHANGES

Internal damage due to frost action, especially when the damage is in the aggregates rather than the cement paste, can lead to considerable expansion in the concrete. Length change measurements can be used to quantify internal damage due to frost.

a. Standards

1. ASTM C 341-89 - Length Change of Drilled or Sawed Specimens of Cement Mortar and Concrete (partly adopted and modified).

2. ASTM C 490-89 - Apparatus for Use in Measurement of Length Change of Hardened Cement Paste, Mortar, and Concrete (partly adopted and modified).

3. ISO 4762/1997 - Hexagon socket head cap screw.

b. Definitions

1. *Length change* - an increase or decrease in the linear dimension of a test specimen, measured along the longitudinal axis, due to causes other than applied load.

2. *Gauge length* is the distance between the reference points which are located in the exposed ends of the gauge studs.

c. Equipment

1. *Length Comparator* - The comparator for measuring length change of specimens shall be designed to accommodate the size of specimen employed and to provide or per-

mit a positive means of contact with the gauge studs and convenient and rapid measurement of lengths of specimens. In respect to the size of the reference specimens the dimension of the comparator should be 170 mm or more.

The comparator for measuring length changes of specimens shall provide a dial micrometer or other measuring device graduated to read in 0.01 mm, accurate within 0.001 mm in the measuring device to allow for small variations in the gauge length of various specimens.

2. *Gauge Studs* - The contact terminals shall be conical, heat-treated surfaces as shown in Fig. 10 (following IS0 4762).

The gauge studs shall be of stainless steel or other corrosion-resistant metal of similar hardness. The gauge studs shall be set so that their principal axes coincide with the principal axis of the test specimen. For the reference specimens the gauge studs shall extent into the specimen 10 ± 2 mm and the distance between the inner ends of the gauge studs shall be 13 ± 0.5 cm.

3. *Reference bar* - The design shall provide a means for checking the measuring device at regular intervals. The reference bar shall have an overall length of approximately the same as the average gauge lengths of the specimens being tested. The bar shall be of a steel alloy having a coefficient of thermal expansion not greater than two millionths per degree Celsius. Each end shall be machined to the same shape as the contact end of a gauge stud, and shall be heat treated, hardened, and then polished. The reference bar shall be provided near one end with a positioning mark, and shall be placed in the instrument in the same position each time a length measurement is taken. The dial gauge setting of the measuring device shall be checked by use of the reference bar at least at the beginning and end of the readings made within a half day when the apparatus is kept in a room maintained at constant temperature. It shall be checked more often when kept in a room where the temperature is not constant.

d. Setting gauge studs

Gauge studs may be glued with epoxy resin in drilled holes.

Drilling Holes should be drilled about 1 mm bigger in diameter than the studs. The location and depth of holes shall be as given in Fig. 10.

The depth of the holes should be such that the gauge studs will project from 3 to 5 mm beyond the ends of the specimen.

Drill a pair of holes in each of two opposite sides of the specimen to compensate for warping and to provide a better average for length change. Position both pairs of holes in a plane containing the longitudinal axis of the specimen and space to be conform to the length of the comparator. The centre of each hole should be at least approximately 25 mm from the end of the specimen. The depth of the hole should preferably be such that the top surface of the gauge stud can extend about 3 mm beyond the surface of the specimen.

e. Determination of gauge length of specimens

Specimens or the comparator shall be rotated slowly while measurement of length is being made. The minimum reading of the dial shall be recorded if the rotation causes a change in the dial reading. Specimen shall be placed in the instrument with the same end up each time a length measurement is taken.

In the case of specimens having gauge studs on the sides, determine the gauge length by direct measurement between the reference points with a suitable scale. Determine the gauge length of specimens having gauge studs in the ends by first measuring the distance between the ends of the gauge studs with suitable callipers and subtracting the lengths of the two gauge studs (see Fig. 10).

f. Evaluation of length change

The calculation of length change has to be done by the following equation:

$$\Delta l_n = \frac{l_n - l_0}{l_s} * 100\% \qquad (I2)$$

where l_n is: $l_n = l_{cs} - l_1 + l_2$.

The symbols are as follows:

Δl_n relative length change after n freeze-thaw cycles

l_0 $l_0 = l_n$ (0 ftc) comparator length of test specimens before first ftc and after the pre-saturation

l_{cs} comparator length of the calibration bar

l_1 comparator length of the calibration bar after n freeze-thaw cycles

l_2 comparator length of specimen after n freeze-thaw cycles

l_s total length of specimen before gluing the lateral sealing (accuracy 0.5 mm, as Section 7.2 Determination of surface scaling b)).

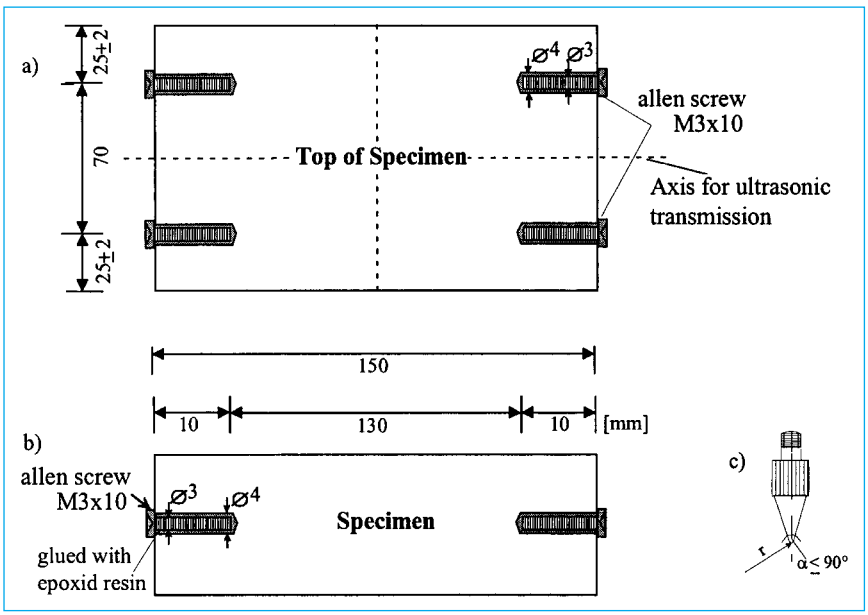

Fig. 10 – Test equipment for measuring the length changes. a) Outline of prepared specimen; b) Sidewise view of prepared specimen; c) Sensing device for dial gauge (comparable arrangement).