Effect of shrinkage on thermal restrained strain in mass concrete

Abstract

The aim of this study is to simulate restrained strain of mass concrete at early age due to combined thermal effect and shrinkages. Firstly, restrained strain caused by differential thermal expansion as well as restrained strains caused by shrinkages are separately computed. Thermal properties such as specific heat, thermal conductivity and thermal expansion coefficient of concrete are estimated by the authors’ mathematical models. The previously proposed adiabatic temperature rise model is used to calculate heat of hydration. Heat of hydration obtained from the modified adiabatic temperature rise model and thermal properties derived from our proposed models are used as the input in a commercialized three-dimensional finite element program to calculate semi-adiabatic temperature and restrained strain. The restrained strains caused by shrinkages are computed based on our existing mathematical models for estimating free shrinkages. Both autogenous and drying shrinkages are considered. The total restrained strain is subsequently computed by the supercomposition concept. It is found that autogenous shrinkage reduces the thermal cracking risk at early age during the insulation curing period while after removal of insulation curing material, drying shrinkage increases the risk of cracking.

Keywords: mass concrete, semi-adiabatic temperature rise, thermal cracking, drying shrinkage, restrained strain

1. Introduction

Mass concrete has been enormously used for large dimension construction such as dams, and mat foundations. In massive concrete structures, the temperature rise due to heat of hydration causes temperature gradients which can induce cracks especially at early age of concrete. Cracking of massive structures can reduce load carrying capacity or service life of a structure by introducing early deterioration, which can lead to excessive maintenance. To avoid cracking due to heat of hydration, one approach is to control the hydration heat of concrete by reducing cement content. Fly ash is one of the pozzolanic materials which can be effectively used as a cement replacing material to reduce hydration heat of concrete.

Thermal cracking is not the only cause of cracking in mass concrete. In general, mass concrete encounters both stresses due to thermal effect and shrinkages. Shrinkage is also another cause of cracking. Then, the effect of shrinkage should be included in the cracking analysis of mass concrete. Total shrinkage of concrete is mainly composed of autogenous and drying shrinkages. Autogenous shrinkage occurs at early age during the progress of hydration reaction. Drying shrinkage is the volume change due to loss of water from the concrete to the
surrounding environment. Shrinkage cracking can take place at either early or later ages. If shrinkage of concrete takes place without any restraint, concrete will not crack. Unfortunately, concrete structures are always subjected to a certain degree of restraint. The compatibility between shrinkage and restraint induces restrained strain. When this restrained strain reaches the tensile strain capacity, the concrete cracks. Development of a computerized program for predicting cracking of mass concrete is beneficial to design mix proportion and construction process. Many researchers [1-4] proposed methods for predicting thermal cracking in mass concrete, however, the effect of shrinkage was not considered in their methods.

From this reason, this study incorporates the effect of autogenous and drying shrinkages, with the use of established free autogenous and drying shrinkage prediction models [5], into the thermal cracking analysis to demonstrate their effects and to make the analysis more close to real. It’s noted here that this study covers only the case of internally restrained thermal stress.

2. Existing Models
2.1 Semi-adiabatic and thermal cracking model

A flow chart of the proposed model for simulating thermal cracking of mass concrete is shown in Fig.1. Heat of hydration and heat produced by pozzolanic reaction, which were obtained from the models proposed by Saengsoy and Tangtermisirikul [6], were used as the input for a commercial FEM program. Thermal properties such as specific heat, thermal conductivity and coefficient of thermal expansion (CTE) are obtained from thermal properties model proposed by Choktawee-karn [4]. FEM program was used to analyze the semi-adiabatic temperature rise of concrete. For the proposed model, three dimensional eight node brick elements were used in the analysis. The couple thermo-mechanical problem was used in the analysis in which heat transfer analysis is solved first. The temperature obtained from the heat transfer analysis is used as the input for the computation of the restrained strain. More details are mentioned below.

2.1.1 Heat Transfer Analysis

By the use of the common heat transfer analysis which was mentioned by many researchers [7-13], together with the derived heat of hydration and pozzolanic reactions and thermal properties from our existing models, the semi-adiabatic temperature can be analyzed.

The governing equation of heat transfer for temperature prediction of mass concrete with consideration of heat of hydration is shown in Eq. (1).

\[
\rho \frac{\partial T}{\partial t} = q_{hy} + \frac{\partial}{\partial x} \left( k_x \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left( k_y \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left( k_z \frac{\partial T}{\partial z} \right)
\]

(1)

Where: \(k_x\), \(k_y\), \(k_z\) are thermal conductivities in x, y and z directions, respectively (kcal/m hr °C). \(\rho\) is concrete density (kg/m³), \(c\) is specific heat of concrete (kcal/ kg °C), \(q_{hy}\) is heat of hydration and pozzolanic reaction (kcal), \(t\) is age of concrete (hr.). \(T\) is temperature of concrete (°C).

Fig.1 A flow chart of the proposed model for simulating thermal cracking of mass concrete

The heat transfer inside the concrete mass is governed by Eq. (1), however, the condition at the concrete surface is different. Conduction process plays an important role in transferring heat within the interior elements. However, for exterior elements, convection plays a dominant role in transferring heat at
the concrete surface. The presence of wind and solar radiation affect the temperature profile significantly and must be considered. The convective heat transfer is involved in transferring heat between surface of mass concrete and environment (between concrete and air). The amount of heat transfer at the surface of concrete can be calculated using Newton’s cooling law. For simplicity, radiation is taken into account together with the convection, through a single convection-radiation coefficient \( h_{cr} \). The convective heat transfer at concrete surface can be expressed as

\[
q = h(T_s - T_a)
\]

(7)

Where: \( q \) is the convective heat flux per unit area, \( h \) is the combined convection-radiation heat transfer coefficient (kcal/m\(^2\) hr \(^\circ\)C), \( T_s \) and \( T_a \) are the surface and air temperature.

In a real mass concrete footing, heat loss to surrounding air is processed by convection. Normally, the side and bottom faces of the footing are covered by subsoil and heat dissipates from concrete to the surrounding soil by conduction process. However, the problem can be simplified by assuming that the amount of heat loss to the surrounding subsoil is assumed to be done by the convection process. This kind of assumption and boundary condition was used in a previous study of other researchers \([11]\).

The model was verified with the test results conducted in the lab and the measured results of many real footings. The verifications were shown in the previous studies of the authors \([4]\). The verifications show that the model is satisfactory for predicting temperature of the measured footings.

### 2.1.2 Restrained Strain Analysis

At each time step, the temperature at each position in the mass concrete, obtained from heat transfer analysis, is used as the input for the restrained strain analysis. The internal deformation and stress in each element are related by Hooke’s law as shown in Eq. (8).

\[
\{\Delta\sigma(t)\} = E(t)\{D\}\{\Delta\varepsilon_{\text{res}}(t)\}
\]

(8)

Where: \( \Delta\sigma(t) \) is the change of stress at the considered age (MPa), \( \Delta\varepsilon_{\text{res}}(t) \) is the restrained strain at the considered age (micron). \( E(t) \) is the modulus of elasticity at the considered age (MPa). \( D \) is the material properties matrix and \( t \) is the considered age.

In case of the absence of external loading, the stresses that cause cracking of early age concrete are induced by restraint of deformations. In the existing model, the restrained strain in mass concrete is caused mainly from the thermal strain due to the temperature change of concrete. The free thermal strain of concrete element subjected to thermal expansion can be calculated from Eq. (9).

\[
\Delta\varepsilon_{th}(t) = CTE(t)\Delta T(t)
\]

(9)

Where: \( \Delta\varepsilon_{th}(t) \) is the free thermal expansion strain. \( CTE(t) \) is the coefficient of thermal expansion coefficient (micron/\(^\circ\)C) and \( \Delta T(t) \) is the temperature change at the considered age (\(^\circ\)C).

### 2.1.3 Verification of the Model to predict thermal cracking of mass concrete

The model was verified with a real concrete footing. Fig. 2 shows a thermal crack at one side of the footing. The size of the footing was 14 x 63 x 1.4 m. The footing was cured by insulation curing for 4.6 days. Cracks were found right after the removal of the insulation materials. This means that cracks might have occurred since early age before the removal of the insulation material.
depth and surface causes internal restraint between mid-depth and surface of the structure. The surface is restrained in tension and mid-depth part is restrained in compression. The analytical results show the same tendency as that occurs in mass concrete as shown in Fig.4. The restrained strain in tension (εres, ten) at top surface is the highest. The εres, ten at top surface obtained from the analysis is compared with the authors’ tested tensile strain capacity of concrete (TSC) and if the εres, ten is higher than tensile strain capacity then the mass concrete structure is predicted crack.

Fig.4 shows the comparison between the predicted εres, ten on top surface and TSC of the concrete. By comparing the analyzed restrained strain with the authors’ test results of TSC [5], the footing was predicted to crack since early age before the removal of the insulation material. From the comparison using the authors’ proposed model and tested TSC, it can be concluded that the model was satisfactory to predict thermal cracking of the footing.

2.2 Shrinkage Model

In this study, the authors’ previously proposed models for predicting free shrinkage of concrete is used in the analysis. Details of the models are given in Ref.[5]. Total shrinkage of concrete is the summation of autogenous shrinkage and drying shrinkage which can be calculated by using Eq. (11). When calculating the total shrinkage, curing period (t0) and type of curing must be considered because they affect values of autogenous shrinkage and drying shrinkage. In case of water-cured, water can penetrate into concrete continuously resulting in insignificant autogenous shrinkage and drying shrinkage during the water curing period especially for thin concrete members. In case of seal-cured concrete or moist-cured (wet burlap), there is no water or insufficient water, respectively, supplied into the concrete, so autogenous shrinkage can occur during the seal curing or moist curing period while there is no drying shrinkage because of no drying on concrete surface. In this condition, the total shrinkage includes the autogenous shrinkage from the time of final setting to the time considered. More details of the autogenous shrinkage model and drying shrinkage model are mentioned in sections 2.2.1 and 2.2.2, respectively.

\[ \varepsilon_{TS}(t, t_0) = \varepsilon_{as}(t, t_0) + \varepsilon_{ds}(t, t_0) \]  

Where:
- \( \varepsilon_{TS}(t, t_0) \) = total shrinkage strain from age of \( t_0 \) to \( t \) (micron)
- \( \varepsilon_{as}(t, t_0) \) = autogenous shrinkage strain from age of \( t_0 \) to \( t \) (micron)
- \( \varepsilon_{ds}(t, t_0) \) = drying shrinkage strain from age of \( t_0 \) to \( t \) (micron)
- \( T \) = time considered (days)
- \( t_0 \) = age at start of drying of concrete (days)

2.2.1 Autogenous Shrinkage Model

Unrestrained autogenous shrinkage was calculated by using a two-phase model concept shown in Eq. (12) for computing concrete autogeneous shrinkage strain. Shrinkage occurs only in paste phase whereas the aggregate phase is considered to restrain the paste shrinkage by their particle interaction. A two-phase material model shown in Eq. (13), taking into account the restrained shrinkage due to aggregate particle
interaction proposed by Tatong, 2001 [14], was adopted in this analysis. This model involved the stiffness, equilibrium condition and strain compatibility of paste phase and aggregate phase.

\[ \varepsilon_w(t, t_0) = \varepsilon_w(t) - \varepsilon_w(t_0) \]  
\[ \varepsilon_w(t) = \varepsilon_{pa}(t) \cdot E_p(t) \cdot (1 - n) \]  
\[ \frac{E_p(t) + E_a}{E_p(t) - E_a} \]

Where: \( \varepsilon_w(t, t_0) \) is the autogenous shrinkage strain from age \( t_0 \) to \( t \) (micron), \( \varepsilon_{pa}(t) \) is the free shrinkage of paste in concrete at the considered age (micron). \( n \) is the volume concentration of aggregate. \( E_p(t) \) is stiffness of paste phase at considered age (kg/cm\(^2\)). \( E_a \) is stiffness of aggregate phase (kg/cm\(^2\)). \( t_0 \) is the age at start of drying of concrete (days). \( t \) is the considered age (days).

### 2.2.2 Drying Shrinkage Model

Unrestrained drying shrinkage was calculated by using Eqs. (14) to Eq. (17). The drying shrinkage model takes into account the effect of cement type, fly ash, water to binder ratio, paste content, curing condition, ambient relative humidity and volume to surface area ratio[13]. All of these parameters significantly affect the drying shrinkage of concrete.

\[ \varepsilon_{ds}(t, t_0) = \varepsilon_{ds}(t, t_0) \cdot \beta(t, t_0) \cdot \beta(h) \]  
\[ \varepsilon_{ds} = \left( 663 - 291 \exp \left[ -7.26 \left( \frac{W}{b} \right)^{1.28} \right] \right) K_1 \cdot K_2 \cdot K_3 \cdot K_4 \]  
\[ \beta(h) = 1.73 \left( 1 - \left( \frac{RH}{100} \right)^3 \right) \]  
\[ \beta(t, t_0) = \frac{(t - t_0) \cdot B \cdot P}{(t - t_0) + A \cdot G \cdot N \cdot F} \]

Where: \( \varepsilon_{ds}(t, t_0) \) is the drying shrinkage strain of concrete from age \( t_0 \) to \( t \) (micron). \( \varepsilon_{ds} \) is drying shrinkage strain of concrete at 150 days of age (micron). \( \beta(h) \) is a factor for considering the effect of relative humidity. \( \beta(t, t_0) \) is the time-dependent function component. \( K_1, K_3 \) and \( K_4 \) are factors considering the effect of the volume concentration of aggregate, fly ash content, and curing condition (curing type and curing period), respectively. \( K_2 \) and \( P \) are coefficients for cement type. \( A \) and \( B \) are factors considering the effect of strength of concrete. \( G \) is a factor considering the effect of volume to surface ratio. \( N \) and \( F \) are factors considering the effect of aggregate content and fly ash content. \( RH \) is relative humidity (%). \( t_0 \) is the age at start of drying of concrete (days). \( t \) is the considered age (days).

Verification of total shrinkage model was performed on concrete specimens exposed to drying condition. Experiments were conducted on concrete with different water to binder ratios, fly ash content, paste content, curing period and curing type. The results obtained from total shrinkage tests by the authors’ research group and data obtained from various researchers were compared with the model of total shrinkage of concrete. An example of verification is shown in Fig.5. It was found that the results obtained from the model were in good agreement with the experimental results [5].

### 3. MODIFICATION OF EXISTING MODELS

#### 3.1 Mechanisms of cracking due to heat of hydration and shrinkage in mass concrete

As shown in Figs.6 and 7, for internal restraint, the restrained strain of mass concrete is contributed from the thermal strain and shrinkage strain. The restrained strain caused by thermal strain in mass concrete is in compression at the inner core and in tension at the surface, leading to risk of thermal cracking. The restrained strain caused by shrinkage strain was separated into two parts. In the first part, autogenous shrinkage strain is...
the strain that occurs in the whole body of the mass concrete. Based on degree of hydration, the highest autogenous shrinkage strain occurs in the center part which has the highest degree of hydration reaction. The second part is the drying shrinkage strain that takes place on the exposed surfaces of the mass concrete. The effect of drying shrinkage exists up to a depth that has no moisture loss. The resulting restrained strain in mass concrete is derived by superimposing the thermal and shrinkage strains as shown in Eqs. (18) and (19).

\[ \varepsilon_{\text{res}}(t) = \varepsilon_{\text{res,th}}(t) + \varepsilon_{\text{res,sh}}(t) \]  
(18)

\[ \varepsilon_{\text{res,sh}}(t) = \varepsilon_{\text{res,as}}(t) + \varepsilon_{\text{res,ds}}(t) \]  
(19)

Where: \( \varepsilon_{\text{res}}(t) \) is the restrained strain resulted from thermal and shrinkage effects, while \( \varepsilon_{\text{res,th}}(t) \), \( \varepsilon_{\text{res,sh}}(t) \), \( \varepsilon_{\text{res,as}}(t) \) and \( \varepsilon_{\text{res,ds}}(t) \) are the restrained strains of concrete by thermal effect, by total shrinkage, by autogenous shrinkage and by drying shrinkage at the considered age, respectively (micron) and \( t \) is the considered age (days).

In general, at early age, insulation curing is recommended to be used for mass concrete for the benefit of temperature control. During this stage there is no loss of water to the surrounding, in other word, drying shrinkage is insignificant during this stage and it is neglected during the insulation curing period. After the removal of insulation materials, there is loss of water at the concrete surface due to evaporation, as a result both autogenous shrinkage and drying shrinkage are considered.

However, in this study, the analysis mainly focuses on the strain that occurs during the first 7 days when the mass concrete is cured by using insulation curing method. The stage after curing is not included in this paper and it will be described in the future study.

An existing model to predict semi-adiabatic temperature and thermal cracking in mass concrete proposed by Choktaweekarn [4] was used in this study. It was modified in this study to take into account the effect of shrinkage in mass concrete. The free shrinkage strain used in the analysis is calculated by using the model proposed by Tongaroonsri [5], as shown in Eqs. (12) to (13). The calculated temperature of concrete at each position is used as the input in the shrinkage model to calculate the autogenous shrinkage at each position. As shown in Fig. 6, the autogenous shrinkage at the mid-depth of mass concrete is higher than the top surface. This is because the temperature at the mid-depth of mass concrete is higher than the surface then the degree of hydration at mid-depth is higher. From this reason, based on degree of hydration, autogenous shrinkage strain at the mid-depth is higher than that at the concrete surface. The free shrinkage strain at each position was input into the FEM program in the form of temperature change as shown in Eq. (20).

\[ \Delta T_{sh}(t) = \varepsilon_{sh}(t) / \text{CTE}(t) \]  
(20)

Where: \( \varepsilon_{sh}(t) \) is the input free shrinkage strain at the considered age (micron). \( \text{CTE}(t) \) is the coefficient of thermal expansion coefficient (micron/°C) and \( \Delta T_{sh}(t) \) is the shrinkage equivalent temperature change at the considered age (°C) and \( t \) is the considered age (days).

In the restrained strain analysis, the restraints from thermal and shrinkage effects are analyzed separately. At the end of the analysis, both restrained strains are superimposed as illustrated in Fig. 6 and Fig. 7.
Fig. 7 Type of restrained strain in different parts of the mass concrete

4. Analytical Results

A concrete block with a size of 5.5 x 11 x 2.5 m was used as an example to simulate the effect of shrinkage on mass concrete. A concrete block is shown in Fig. 8. This concrete block was assumed to be cured by insulation curing for 7 days. Mix proportion and 28-day compressive strength of concrete used in the analysis are shown in Table 1.

Table 1 Mix proportion of concrete (in kg/m³)

<table>
<thead>
<tr>
<th></th>
<th>Cement</th>
<th>Water</th>
<th>Sand</th>
<th>Gravel</th>
<th>28-day Compressive Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>294</td>
<td>150</td>
<td>860</td>
<td>1123</td>
<td>25.8</td>
</tr>
</tbody>
</table>

Fig. 8 An example concrete block

A flow chart of the analytical process for simulating cracking of mass concrete is shown in Fig.9. The adiabatic temperature was obtained when knowing mix proportion. Concrete mix proportion and properties of cementitious materials were used for calculating adiabatic temperature. Predicted adiabatic temperature is shown in Fig.10.

Fig. 9 A flow chart of the analysis for simulating cracking of mass concrete

Fig. 10 Predicted adiabatic temperature

Thermal properties such as specific heat, thermal conductivity and cumulative heat generation, dimension of structure, ambient temperature, boundary conditions and convection heat transfer coefficient were used as the inputs to analyze the semi-adiabatic temperature rise of concrete.

Predicted semi-adiabatic temperatures are shown in Fig.11. The results in Fig.11 show that the temperature at location B (mid-depth) is higher than that at location A and C (the top and the bottom surfaces, respectively).

Fig. 11 Predicted semi-adiabatic temperatures at location A, B and C (top, mid-depth and bottom surfaces, respectively)
From Fig.11, the temperature gradients between center and surface of concrete were used to analyze the restrained strain due to differential thermal deformation where modulus of elasticity, Poisson’s ratio and coefficient of thermal expansion were used as the input of the computation.

Restrained thermal strains at locations A, B and C in Fig.8 of concrete are shown in Fig.12.

Fig.12 Restrainted thermal strain at surface of concrete

Fig.12 shows the restrained strain without effect of shrinkage consideration. While $\varepsilon_{\text{res,A}}$, $\varepsilon_{\text{res,B}}$ and $\varepsilon_{\text{res,C}}$ are restrained thermal strains at locations A, B and C, respectively. The restrained strain by thermal expansion at the surface of concrete shows two peak values, one at early age and another at the day the insulation curing material is removed (7 days), and after that decreases continuously. It should be noted that the effect of shrinkages in the 2nd peak (at the time of insulation material removal) is not discussed. The target is to demonstrate effect of autogenous shrinkage at the early age (before insulation material removal) and drying shrinkage after drying exposure (after removing the insulation material). At the point of insulation material removal, the effect of autogenous shrinkage is smaller than that at the earlier age. Also, the effect of drying shrinkage is still not seen at that time since the concrete surface is just exposed to drying.

Fig.13. It can be seen that the inner portion (B) is in tension while the near surface portions (A and C) are in compression because the inner portion with higher temperature has higher autogenous shrinkage. The inner portion is in self-equilibrium with the lower autogenous shrinkage portion near the surface.

The analytical results of restrained strain at mid- depth (B) and surface (A) are shown in Fig.14. Fig.14 shows that autogenous shrinkage strain at the mid- depth is higher than that near the top surface due to higher temperature and degree of hydration, while the lowest autogenous shrinkage at the top surface is due to lower temperature and moisture content (due to drying near the exposed surface), leading to lower degree of hydration reaction, especially at the early age.

Fig.13 Restrainted autogenous shrinkage strains

Fig.14 Different autogenous shrinkage at mid-depth (location B) and surface layer (location A) due to different degree of hydration

To consider effect of restrained strain by shrinkage, free shrinkage strains were used as input at each location. Firstly, the differential autogenous shrinkage came from the effect of temperature gradient in Fig.11. These temperatures were used to compute the degree of hydration, and degree of hydration affects autogenous shrinkage as shown in
the discussions. The free shrinkage strain at each position was input into the FEM program in the form of temperature change as shown in Eq. (20). The restrained autogenous shrinkage strain was computed separately as shown in Fig.13 and the summation of the restrained strains by thermal and autogenous shrinkage effects are shown in Fig.15.

Fig.15 Combined restrained thermal and autogenous strains

\[ \varepsilon_{\text{res},A'}, \varepsilon_{\text{res},B'} \text{ and } \varepsilon_{\text{res},C'} \] are the combined restrained thermal-autogenous shrinkage strain at locations A, B and C, respectively. It can be seen from Fig.15 that the combination of the autogenous shrinkage strain with thermal strain results in reduction of restrained strain near the top surface of the concrete (comparing \( \varepsilon_{\text{res},A} \) with \( \varepsilon_{\text{res},A'} \)). The restrained strain by only thermal strain (\( \varepsilon_{\text{res},A} \)) is reduced by about 10 micron by the restrained autogenous shrinkage strain.

The restrained total shrinkage strain was also computed separately as shown in Fig.16. Free total shrinkage strain in Fig.17 was used as input at each location.

Fig.16 Restained total shrinkage strains

Fig.17 Free total shrinkage strains at the top surface of concrete

Fig. 17 shows the restrained strain caused by total shrinkage (summation of autogenous and drying shrinkages). Autogenous shrinkage reduces restrained strain during the insulation curing period but drying shrinkage increases restrained strain of the mass concrete after the insulation curing period. It was assumed that there was no drying shrinkage during the insulation curing period.

After combining restrained strain due to total shrinkage with thermal restrained strain, the net restrained strains in Fig.18 decrease at early age by the effect of autogenous shrinkage. After insulation curing material is removed (7 days), restrained drying shrinkage strain shows great effect on tension zone and leads to cracking at the mass concrete surface when the net restrained strain is greater than tensile strain capacity (TSC in Fig.18). It is therefore recommended not to let the exposed surface of concrete dry immediately after the removal of insulation.
The consideration of autogenous and drying shrinkages will result in a more realistic prediction of cracking in mass concrete footings. It was found that the effect of drying shrinkage is more significant than the effect of autogenous shrinkage for the internally restrained thermal stress. It’s noted that creep and relaxation are not included in this study. For future study, the effect of creep and relaxation of concrete might be included to the computation for more precise prediction.

5. Conclusion

From the analytical results, it was found that autogenous shrinkage reduces the risk of cracking especially at the early age before the removal of insulation curing material. However mass concrete can be at risk by the effect of drying shrinkage after the removal of the insulation curing material. Care must be taken to prevent excessive loss of moisture.

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7. References


