DURABILITY MODEL OF JOINTLESS INSULATION SYSTEMS (JLIS) OF EXTERNAL PARTITIONS

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Abstract
The paper presents durability model of jointless insulation systems (JLIS), which uses styrofoam. A model is based on changes of diffusion coefficient which was investigated during accelerated ageing process in research cabin.

Streszczenie
W artykule przedstawiono model trwałości bezspoinowego systemu ociepleniowego (BSO) z warstwą izolacji wykonaną ze styropianu. Model trwałości został oparty na podstawie zmian współczynnika dyfuzji w trakcie badań w komorze starzeniowej.

Keywords: **External thin-layer plasters; Simulated and accelerated ageing; Durability; Diffusion.**

1. INTRODUCTION

The durability of the insulation system changes during its use. The existing models of forecasting of construction materials durability are based on measurements of changes features such as: durability, ground adhesion, open porosity and decreases of mass. Each selected feature which is able to characterize a process of waste is a representative feature for a representative material.

2. FACTORS OF DESTRUCTION

The weakest element decides about durability of an insulation system. Experiences and conducted investigations show that the weakest element of this set is a plaster. This layer is exposed to the influence of external environment factors which cause many micro scratches. Water penetrates through these scratches inside a plaster and causes frost effects and physics-chemical process.

2.1. An influence of carbon salts

Cement is used very often during production of mixtures of glue mortars and mineral plasters. Oxide of calcium, which is produced during a hydration process combines with water. These two ingredients form calcium hydroxide $Ca(OH)_2$, which is water-soluble. This solution is an alkaline which comes in reaction with acid substances. The calcium hydroxide settles between a glue wad and a plaster. It is a result of influence a weather and moisture factors.
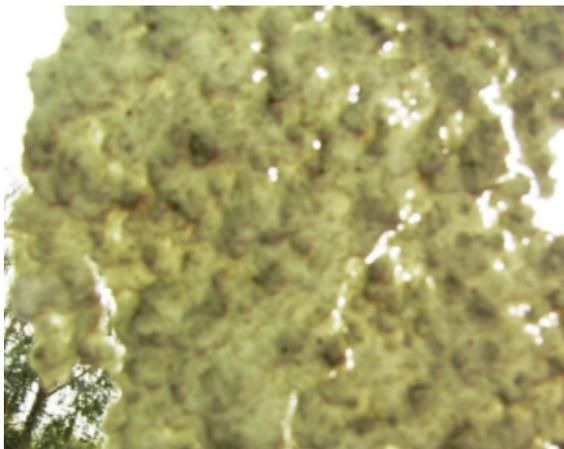
It happens especially in autumn–winter period.

Leaks in the structure of a topcoat plaster permit to penetrate the plaster by a carbon dioxide which is contained in the air. (Fig. 1, 2)
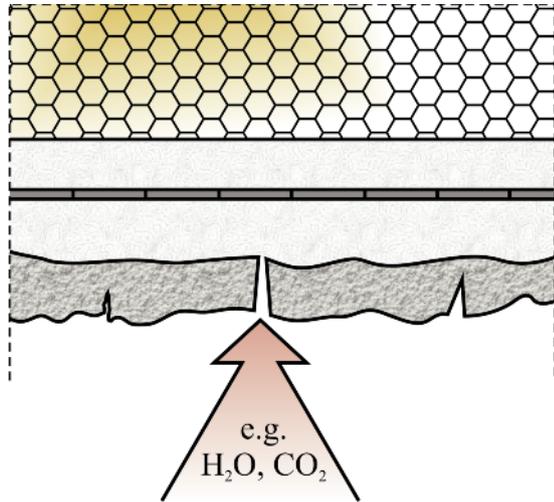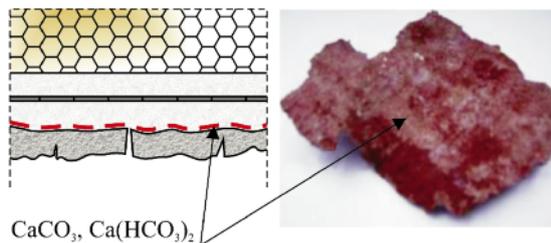
Figure 1.
A penetration diagram of substances from environment

The carbon dioxide is water-soluble.

It creates a carbonic acid. Its dissolubility depends on temperature.

The speed of carbonatization process depends on porosity of a plaster and a pad layer as well as on a leak in a plaster layer and content of carbonization dioxide in the air.

During production process of acrylic plasters the following are used: a polymeric binder, a mineral filler, incrasative resources (derivatives and cellulose), water (repellent resources), conserving resources, humectants and pigments

An acrylic plaster during technology of realization of the JLIS system usually lies on a glue foundation, where the cement is also the binder.

Process of carbonatization is also set in a glue layer under an elevation surface (Fig. 3, 4), but its course is slower than in mineral plasters. That is because the structure of the acrylic plaster is more compact and tight. Changes in structure of the acrylic plaster are shown in researches conducted in ageing chamber. These changes include crystallization of carbonate of calcium and magnesium.

The carbon dioxide contained in water provides carbonates contained in water as solvable acid carbonates $Mg (HCO_3)$.

Figure 2.
Leaks in the plaster

Figure 3.
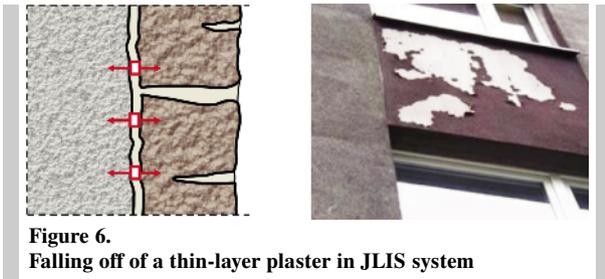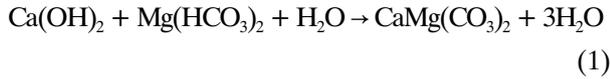**The calcium carbonate settles down under the plaster**
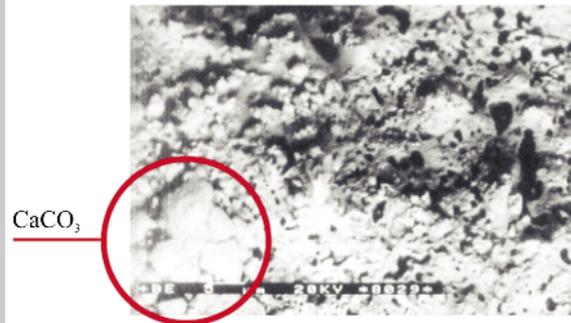
Figure 4.
The calcium carbonate in a thin-layer mineral plaster after 400 cycles in an ageing chamber
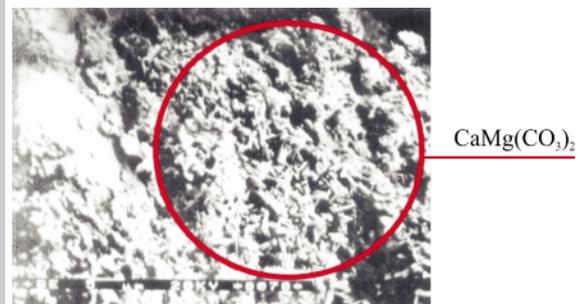
Figure 5.
The carbonate of calcium and magnesium after 400 cycles in an ageing chamber

Presence of magnesium carbonate is caused by use of carbon fillers and the influence the rainfall in the acrylic plaster. Calcium hydroxide reacts with magnesium carbonate and arises the hard solvable carbonate of calcium and magnesium.

$$Ca(OH)_2 + Mg(HCO_3)_2 + H_2O \rightarrow CaMg(CO_3)_2 + 3H_2O \tag{1}$$

Figure 6.
Falling off of a thin-layer plaster in JLIS system

In both cases the increase of carbonates of calcium and magnesium causes the growth of volume. It leads to loss of adhesiveness of the plaster and falling off from the glue layer.

2.2. An influence of temperature and moisture

The thin-layer plaster in JLIS system is under the influence of external factors like rain and sun radiation. Because of coupling flows of moisture and heat extensions and the cramp of material as well as setting phase transformations, the uncontrolled tensions come into being. They initiate changes in structure of the glue layer and the plaster layer. Leaks in the plaster layer make possible the penetration of a rain water inside the JLIS structure possible. The quantity of taken over moisture we qualify by adding up after the time of moisture stream, which penetrates the JLIS.

$$Q = \int_{t_1}^{t_2} j \; dt \tag{2}$$

The process of rain water absorption during rainfalls is dominated by macro pore, which has got larger diameters, however, the process of redistribution inside the material goes through pores with smaller diameters.

Capillary strengths predominate in transportation of moisture. In isothermal conditions the quantity of the received moisture Q will be proportional to quadratic root with time $t\left(\sqrt{t}\right)$.
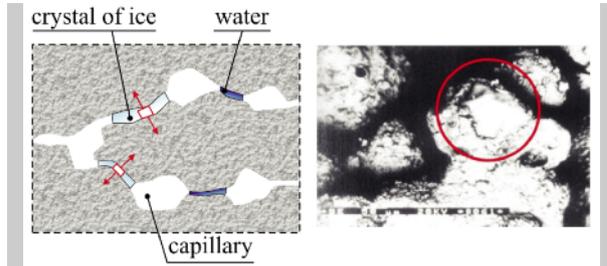

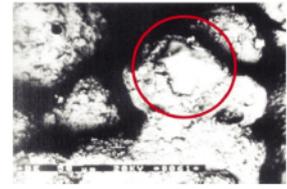**Figure 7.**
Forces in capillars

Figure 8.
The destruction of the binder

Water changes into ice in the winter period. Water freezing in capillaries depends from external forces. These forces cause an increase of water pressure in narrow pores. Temperature of freezing water falls with growth of pressure. So the greatest decrease of freezing temperature is in the smallest pores.

The smallest pores ($r_{ef} > 500$ Å) have got free water, which freezes depending on quantity of dissolved salts or over-cooling in temperature 0-10°C.

### 2.3. The thermal influence as a result of solar radiation absorption

The plaster is an external element of the JLIS system. Solar radiation affects it. Producers offer a wide range of plaster colors. There are many dark plasters. They have high absorption properties of solar radiation. The temperature of air outside changes with the solar radiation. The intensity of solar radiation depends on the sun position during a day or a year. It also depends on degree of sun rays absorption. If the sky is cloudy, the degree of absorption is smaller. Temperature of the air outside increases when the weather is sunny. So temperature of the air outside and the intensity of solar radiation exert an influence on temperature on an external part of the JLIS system. A connection of solar radiation with temperature of external air was defined by Mackey and Wright as sunny temperature of the outside air. This sunny temperature is defined as hypothetic temperature of air outside. The heat transfer through the sun barrier would be the same as under the insolation near real temperature of external air.

This formula lets calculate the sunny temperature of the air outside:

$$T_s = T_z + \frac{\alpha \cdot I_c}{\alpha_z} \qquad (3)$$

where:

T_s – sunny temperature of the air outside

T_z – temperature of the air outside

α – absorption of solar radiation

I_c – intensity of solar radiation

α_z – taking over the warmth on the external side sunny area, shadow

Figure 9.
Sunny temperature of the air outside. T_s – sunny temperature, T_z – temperature of the air outside
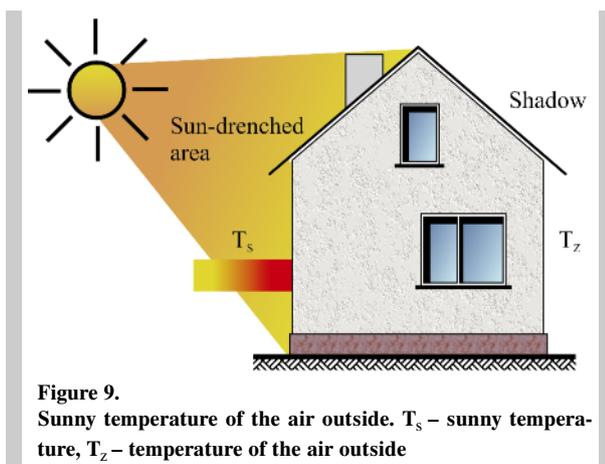
The sunny temperature depends on the temperature of the air outside and intensity of solar radiation. It also depends on extent of plasters absorption. Absorption is a relation between amount of solar radiation which penetrates the plaster and a stream of solar radiation. To calculate the value of hypothetic sunny temperature, which is on the layer of the plaster we determine maximum value of solar radiation and intensity, which were noticed in Katowice area in June 2000.

The value of the plaster absorption is 0.85.

$$T_s = 34.3 + \frac{0.85 \cdot 954.7}{17} = 82°C \qquad (4)$$

The possible temperature on the plaster's layer is over 80 °C.

The other method which lets calculate the value of maximum temperature of the plaster's layer, according Stephan's rule is the temperature of balance which we can count using the following formula:

$$T_{równ} = \sqrt[4]{\frac{\alpha}{\varepsilon} \cdot \frac{I_c}{\sigma}} \qquad (5)$$

Where:

α – Stephan-Boltzman constant,

$$T_{równ} = \sqrt[4]{\frac{0.85}{0.80} \cdot \frac{954.7}{5.67 \cdot 10^{-8}}} = 365.7K = 92.7°C \qquad (6)$$

The balance temperature of a dark plaster according equation no. 6 is about 90 °C.

So large hesitations during a day and a night and during the whole period of using this plaster causes tensions evoked by cramp and extension of this material. That is why there are a lot of cracks. The styrofoam system shrinks in high temperature. The stability of the styrofoam system is guaranteed due to temperatures from 70-80°C.
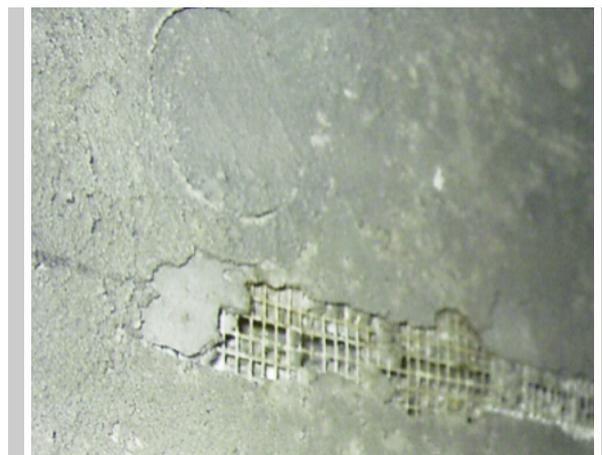
Figure 10.
Changes in JLIS system as a result of high temperatures

3. DIFFUSION MODEL OF DURABILITY

Results of the above mentioned researches showing the changes in JLIS structure. These changes are connected with accelerated ageing process realized in laboratory chamber. It is necessary to determine the waste depends on time. Treating waste as a necessary process of technical changes of the JLIS system, we are able to determine a general model of waste.
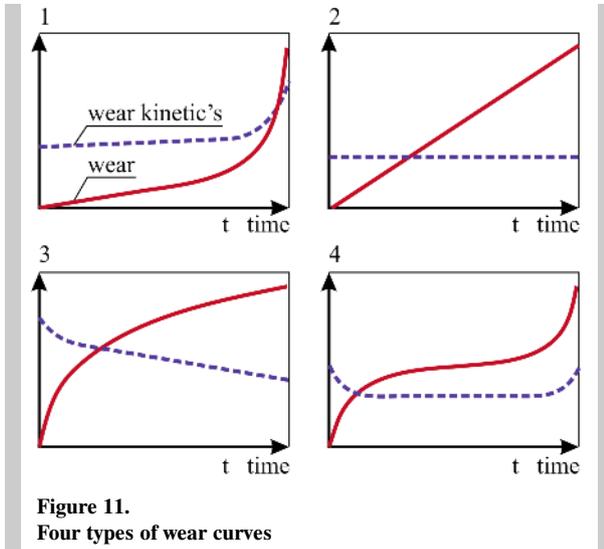
$$Z(t) = Z_0 + \dot{Z}(t) \cdot t \qquad (7)$$

Where:

Z_o – the initial value of waste

$\dot{Z}(t)$ – the waste kinetics

t – time

Among many empirical functions it is possible to choose four basic.

Figure 11 represents their graphic interpretation.

Figure 11.
Four types of wear curves

Curve no. 1 shows waste when its speed increase. Curve no. 2 shows decrease of waste, when speed does not change a lot. Curve no. 3 shows waste in an initial phase and decrease its speed. Curve no. 4 is similar to Lorenz curve, where we can point three types of waste: an initial term connected with stabilization of a material, a term of constant waste and term of accelerated waste.

A parameter which determines JLIS waste and changes in the system is a coefficient of diffusion D.
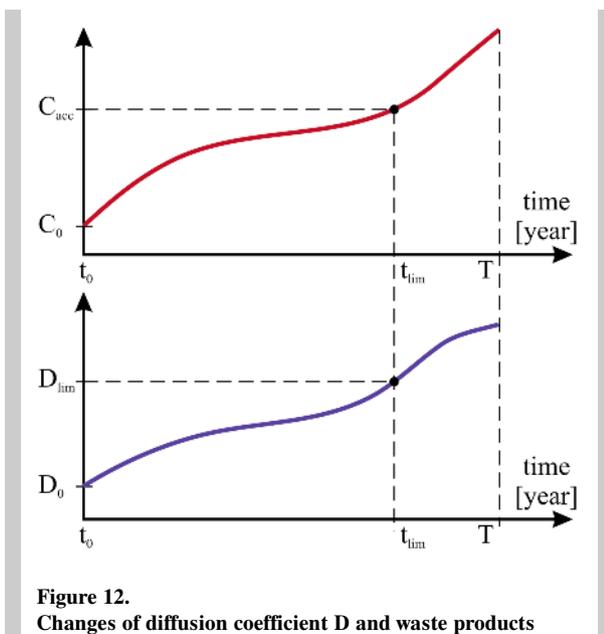
Figure 12.
Changes of diffusion coefficient D and waste products

Changes of coefficient of diffusion D and concentration of waste products are shown in figure no. 12.

According to the prior researches, JLIS function of ageing is determined by diffusion coefficient.

$$D(t) = \chi_0 D_0 [1 + \chi(t)] \qquad (8)$$

where:

D_0 – the initial value of coefficient of diffusion $[m^2/s]$

χ_0 – a parameter which determines an influence of structural imperfections on capacity of the JLIS [-], $\chi_0 \geq 1$,

$\chi(t)$– ageing function which shows an impact of structural imperfections and external factors on JLIS capacity during particular time.

The ageing function based on prior researches.

$$\chi(t) = at \exp(bt) \qquad (9)$$

Where:

a, b – kinetic parameters which characterize the JLIS waste, which is expressed by diffusion coefficient D.

$$D(t) = \chi_0 D_0 [1 + at \exp(bt)] \qquad (10)$$

Function number ten in depending on kinetic parameters can shape as waste curves mentioned above.

A parameter $\chi_0 = 1$ was accepted for the JLIS system, which was made according to ITB instruction. This JLIS was devoided of an imperfection influence on isolation layer. When the value of coefficient of diffusion in individual periods of time is known, it is possible to determine kinetic parameters which characterize particular JLIS.

Using researches done by Mr. J. Bochen e.g. [5] about durability of plasters, the acceleration coefficient of environment, which exists in PBS chamber was calculated. The number of days with 0°C temperature was very important. This coefficient was compared with natural environment. Using climatic data for Katowice area from year 2000, the time in natural environment, which is comparable with 50 cycles in laboratory environment was determined.

$$K_{50} = \frac{N_T(real) \cdot 1[year]}{N_T(symul)} = \frac{54}{50} = 1.08 \approx 1\,year \qquad (11)$$

where:

N_T(real) – number of days with 0°C temperature, during one year.

N_T(simul) - amount of appearances of 0°C temperature during 50 cycles of researches.

When the coefficient of diffusion in styrophoam is constant and stable, the ageing function for JLIS is determined by changes of diffusion coefficient in a foundation layer and in a thin-layer plaster.

Using results of researches of diffusion coefficient at the beginning, after 50 cycles and after 100 cycles the following formula was created. It is based on 9-13 formulas.

For JLIS with an acrylic plaster:

$$2.86 \cdot 10^{-7} = 3.60 \cdot 10^{-7} \left[1 + a_a \cdot 1 \cdot \exp(b_a \cdot 1) \right] \quad (12)$$

$$2.94 \cdot 10^{-7} = 3.60 \cdot 10^{-7} \left[1 + a_a \cdot 2 \cdot \exp(b_a 2) \right] \quad (13)$$

For JLIS with a mineral plaster:

$$4.52 \cdot 10^{-7} = 4.53 \cdot 10^{-7} \left[1 + a_m \cdot 1 \cdot \exp(b_m \cdot 1) \right] \quad (14)$$

$$4.61 \cdot 10^{-7} = 4.53 \cdot 10^{-7} \left[1 + a_m \cdot 2 \cdot \exp(b_m \cdot 2) \right] \quad (15)$$

When we solve the above formulas, we receive a durability function JLIS, which depends on diffusion coefficient.

For JLIS with an acrylic plaster:

$$D(t) = \chi_0 \cdot D_{0a} \cdot \left[1 - 0.4609 \cdot t \cdot \exp(-0.8075 \cdot t) \right] \quad (16)$$

For JLIS with a mineral plaster:

$$D(t) = \chi_0 \cdot D_{0m} \cdot \left[1 + 0.0051 \cdot t \cdot \exp(0.5596 \cdot t) \right] \quad (17)$$

where:

D_{0a}=3,60·10⁻⁷ the initial value of diffusion coefficient for a foundation layer and an acrylic plaster [m²/s]

D_{0m}=4,53·10⁻⁷ the initial value of diffusion coefficient for foundation layer and a mineral plaster, based on functions (16) and (17) is showed below:
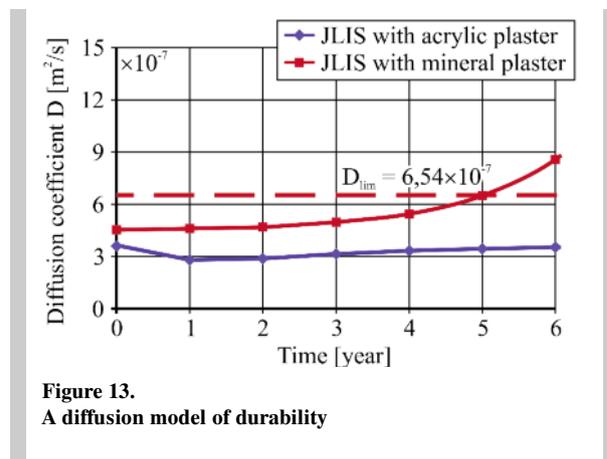

Figure 13.
A diffusion model of durability

The acceptable value is the value of diffusion coefficient for a foundation layer when the JLIS destruction is a result of cracking and falling off a thin layerplaster.

This JLIS model confirms, that durability of JLIS's system lasts 5 years.

When we take into consideration an influence of a structural imperfection in a styrofoam layer, the parameter χ_0 is determined by:

$$\chi_0 = \frac{D_{imp}}{D_0} \quad (18)$$

Where:

D_o – the value of diffusion coefficient JLIS, without an imperfection [m²/s]

D_{imp} – the value of diffusion coefficient JLIS with an imperfection [m²/s]

4. CONCLUSIONS

Leaks of a plaster layer, which was made because of environmental factors and bad workmanship cause an intensive penetration of carbon dioxide, sulphur and water into the JLIS system. This unfavourable phenomenon generate the carbonatization process of the plaster and reinforcement. A crystallization of carbon salts under the plaster layer is a result of this process.

The result of salt expansion is a tension, which causes falling off of the plaster. Tightening the top layers of JLIS structure causes a temporary improvement of its quality, but the durability of the whole system is lower. The intensive flow of moisture causes cramping and swelling of the plaster. Because of this phenomenon smaller and bigger cramps appear in this system. Water penetrates the JLIS through these cramps. If the reinforcement is badly protected against water influence, water changes into ice and blows up a glue layer.

A diffusion coefficient of water steam is a parameter which describes well waste of the JLIS system. Changes of its value shows changes of this system.

The model of the JLIS which was made for a mineral plaster, using above mentioned diffusion coefficient, confirms that durability of this system lasts for about 5 years. The parameter which determines an influence of the structural imperfection lets test the condition of the insulation system. It is possible to observe cramps and dropping out of a plaster after 2-3 years. It is a result of the bad workmanship. The system of JLIS layers, technical details and weather conditions should be such as in the currently applicable ITB instruction no. 334.

If the quality of material is high and workmanship is good, durability of the insulation system is 5 years. After this period a user should carry out repair of the system. This insulation system must be controlled every year. In the above mentioned example only small cracks, small spots and also very small damages in the bottom part of a building were noted. Stains can be removed by washing a wall. Next the layer must be protected and painted one more time. These procedure makes the insulation system clean and well protected for next years.

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