Durability of Building Materials and Components in Agricultural Environment

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Abstract

The agricultural environment has its main influence on floor surfaces in buildings and structures. The floor surfaces are exposed to a chemical and physical environment, which is very aggressive, because of different factors originating from manure, drinking water and feed stuff.

Floors and other building components of farm buildings show different degrees of degradation. Concrete material, which is often used in floors and walls need a high material quality to resist against the chemical and physical attacks.

This paper will present a brief review of recently performed research about durability of building materials and components in agricultural environment.

Keywords: Farm buildings, agricultural environment, durability, concrete material, wood material, steel material.
1 Introduction

In agricultural production one can roughly distinguish between the following types of farm buildings: 1) animal houses for cattle, pigs and poultry 2) slurry pits and silos for manure and 3) storage structures for agricultural products.

Farm buildings are built of different materials and components, such as concrete material (floor and foundation structures); concrete, steel or wood materials (wall structures) and steel or wood materials (roof structures).

The agricultural environment, both inside and outside farm buildings, is very aggressive. The biological activity in organic matter produces aggressive substances towards building materials as well as towards animals and persons. It is especially the chemical environment, which influences the building materials. Inorganic and organic acids, natural manure and different salts of artificial manure products have a great impact on the durability of building materials and components in farm buildings.

Research about durability of building materials and components in agricultural environment has been focused on concrete for agricultural purposes. Most of this research has been carried out at different institutes and universities in Belgium, Ireland, the Netherlands and Sweden. Within the organisation European Agricultural Engineers (EurAgEng) a working group (SG15/TG1) was formed in 1996 with the aim to put together performed research and plan for new research activities within this area of durability research.

This paper will present a review of recently performed research about durability of building materials and components in agricultural environment.

2 Agricultural environment

2.1 Animal houses

The chemical and physical environment of animal houses can be divided into two distinct parts: 1) the air environment and 2) the wet environment on floors, walls and equipment.

The air environment depends on a wide variety of influences, such as the characteristics of the housing system (layout and volume of the building, type of roof, thermal insulation, ventilation, handling of manure), the types of animals housed and the physical environment (sun radiation, temperature, air speed, relative humidity). There are a large number of gases in the air environment but most of them occur in low concentrations. The presence of manure also considerably influences the air environment.

Table 1 presents the recommended maximum concentrations of the gases in stables, which occur in the highest concentrations. Measurements of concentrations of ammonia and carbon dioxide at floor level up to 0.3 m above floor level demonstrated the following [1]:

- NH₃ concentrations range from 2 – 50 ppm (yearly mean: 4 – 13 ppm);
- NH₃ and CO₂ concentrations are considerably lower during summer periods than in winter periods;
- the use of natural or mechanical ventilation has no significant influence on NH₃ and CO₂ concentrations. Too low ventilation rates cause an increase of especially the CO₂ concentration;

The content of dust from animal houses originates primarily from the animals, the fodder, the straw material and the manure.
Table 1. **Recommended** maximum concentrations of gases and dust in stables [1].

<table>
<thead>
<tr>
<th>Gas /dust</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>3000 ppm</td>
</tr>
<tr>
<td>CH₄</td>
<td>500 ppm</td>
</tr>
<tr>
<td>H₂S</td>
<td>0.5 ppm</td>
</tr>
<tr>
<td>NH₃</td>
<td>20 ppm</td>
</tr>
<tr>
<td>dust</td>
<td>1.5 mg/m³</td>
</tr>
</tbody>
</table>

The acceptable range of air temperature strongly depends on the type of animal housed. Table 2 contains acceptable temperature ranges for housing systems. These temperatures are valid for a zone ranging from floor level to 0.3 m above floor level. The floor is assumed to be dry, not heated and made of concrete.

Table 2. **Acceptable extreme temperatures** in housing systems for animals [1, 2, 3].

<table>
<thead>
<tr>
<th>Animals</th>
<th>Temperature [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>dairy cattle, fattening bull</td>
<td>5 - 20</td>
</tr>
<tr>
<td>young cattle&lt; 1 yr</td>
<td>10 – 24</td>
</tr>
<tr>
<td>pigs &lt; 20 kg</td>
<td>23 – 33</td>
</tr>
<tr>
<td>fattening pigs</td>
<td>17 - 25</td>
</tr>
<tr>
<td>sows</td>
<td>12 - 25</td>
</tr>
<tr>
<td>broilers &lt; 2 months</td>
<td>17 – 33</td>
</tr>
<tr>
<td>broilers</td>
<td>15 - 22</td>
</tr>
<tr>
<td>laying hens</td>
<td>15 - 22</td>
</tr>
</tbody>
</table>

The highest concentrations of aggressive substances are found in the wet environment on the floors in animal houses. The wet environment consists of minerals and salts of different species. It has been concluded at analysing the chemical composition of manure and silage that the highest concentrations of chloride has been found in poultry manure, 0.34 % and the lowest has been found in cattle manure, 0.05 % [4].

The wet environment on the floors in animal houses also consists of high concentrations of organic acids. It has been concluded at analysing the chemical composition of samples of organic matter from different places in houses for pigs, cattle and poultry, that there are concentrations of acetic acids up to 8 %. The acid concentrations seem to increase when the time for the fermentation process in the organic matter increases [4].
2.2 Manure and silage storage systems

Three types of manure can be distinguished:

1. Liquid manure, which contains urine with a maximum dry matter content of 3%.
2. Slurry, which is a mixture of urine, faeces, feed residues and water. The slurry has to be regularly mixed to facilitate pumping from the storage. The dry matter content is 2-20%. Table 3 contains information on the chemical composition of slurry from three animal categories.
3. Solid manure, in which about 90-95% of the nitrogen is organically bound. This is only 30-50% and about 5% for slurry and liquid manure respectively [2].

Table 3. Chemical composition of slurry, in g/l [5].

<table>
<thead>
<tr>
<th>Chemical component</th>
<th>Cattle</th>
<th>Fattening pigs</th>
<th>Laying hens</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (N-Kj)</td>
<td>3.8 - 7.6</td>
<td>4.3 - 11.5</td>
<td>5.9 - 15.7</td>
</tr>
<tr>
<td>Ammonium (NH₄-N)</td>
<td>0.2 - 4.4</td>
<td>1.3 - 5.5</td>
<td>2.6 - 9.2</td>
</tr>
<tr>
<td>Phosphate (P₂O₅)</td>
<td>1.3 - 3.1</td>
<td>3.6 - 6.6</td>
<td>0.3 - 12.0</td>
</tr>
<tr>
<td>K₂O</td>
<td>3.3 - 11.0</td>
<td>2.0 - 6.1</td>
<td>0.3 - 11.5</td>
</tr>
<tr>
<td>CaO</td>
<td>1.6 - 3.3</td>
<td>2.4 - 4.4</td>
<td>0.9 - 19.6</td>
</tr>
<tr>
<td>MgO</td>
<td>0.8 - 1.6</td>
<td>0.6 - 2.0</td>
<td>0.1 - 2.4</td>
</tr>
<tr>
<td>Cl⁻</td>
<td>1.8 - 4.2</td>
<td>0.6 - 3.3</td>
<td>0.1 - 3.2</td>
</tr>
<tr>
<td>SO₄²⁻</td>
<td>2.0 - 3.0</td>
<td>1.0 - 2.0</td>
<td>2.0 - 4.0</td>
</tr>
<tr>
<td>Acetic acid</td>
<td>5.5 - 7.0</td>
<td>3.2 - 11.0</td>
<td>11.0 - 22.0</td>
</tr>
<tr>
<td>Propionic acid</td>
<td>1.6 - 2.0</td>
<td>0.7 - 3.0</td>
<td>4.0 - 7.5</td>
</tr>
</tbody>
</table>

PH                     | 7.0 - 8.8 | 7.3 - 8.6      | 6.7 - 8.3   |
Dry matter (% m/m)      | 7 - 9     | 4 - 11         | 11 - 18     |

Most silage is stored on concrete, either in bunker silos (base slab plus walls) or on a base slab only. The dry matter content of fresh, compacted silage is about 18-24%. The quantities of silage effluent coming out of the fresh silage can be up to 200 l per ton of silage (pressed pulp: 10-50 l/ton; maize: 50-100 l/ton; brewer’s grains: 100-150 l/ton; wet grass: 100-200 l/ton). The effluent produced during storage of e.g. grass and maize is drained towards the front of the base slab, collected and pumped into a slurry pit [6, 7, 8]. The pH value of the effluent can be 3.5-4, the main acids being lactic and acetic acid.

Fertilizer can also be stored on slabs. It may contain considerable amounts of nitrogen (up to 25%), phosphate (P₂O₅; up to 45%), potassium (K₂O; up to 60%), calcium (CaO; up to 55%), manganese (MgO; up to 25%) and sodium (NaO; up to 5%). In horticulture, liquid fertilizers containing e.g. Ca²⁺, Mg²⁺, K⁺, PO₄³⁻, SO₄²⁻, CO₃²⁻ or NO₃⁻ are increasingly being used [9].

Potatoes are stored at temperatures of about 5 °C and treated with fungicides containing acids or chlorides. Germination retardants contain chloride. Resistance against mechanic loading, for instance by loading by lift trucks, should be taken into account.
3 Durability of Building Materials and Components

3.1 Floor Structures
In animal houses there are three main types of floors; solid floors, unperforated floors that are laid directly on the ground and slatted floors, which permit drainage of urine and faeces from the animals [10]. The major advantages of slatted floors are the complete omission of straw and an appreciable reduction in labour time requirement for cleaning of the floor. The animals are cleaner because of the fast removal of the manure and areas of possible reduction in the immediate vicinity of the animals are eliminated [11].

These floor types are all made of concrete material. The solid and unperforated types are mostly made of ready mix concrete but the slatted types (slatted beams and cassettes) are mainly made of precast concrete. In 1991 work was started to establish an European standard [12] for slats, such as single beams, twin slats, multiple slats and perforated panels. The standard classifies the slats according to cattle on one hand and pigs, sheep and goats on the other hand. Requirements are given for concrete compounds, concrete strength, concrete quality, position of the reinforcement, floor slats geometry and surface characteristics.

According to the European standard the demands of the concrete quality for floor slats are that the water/cement ratio should not exceed 0.45 and the cement content should not be less than 350 kg/m³ at a concrete cover ≥ 40 mm.

Degradation

Several field investigations have shown severe degradation on concrete slats [13, 14]. The degradation of the concrete material is due to the aggressive environment on the floors in the animal houses. It has been concluded that there are three main degradation mechanisms; the influence of the organic acids as lactic and acetic acid, the reinforcement corrosion and the mechanical wear.

Most of the organic acids, especially acetic acid come from the manure. The lactic acid originate from acidified meal/water mixtures and is therefore the main source of severe concrete degradation near or in between the feed and water supply.

Lactic and acetic acid are very aggressive, because their reaction with free lime of the concrete produces very soluble calcium salts [15]. When those salts are leached, the concrete porosity will increase and the pH in the pores will decrease. Following factors, besides water/cement ratio and cement content, influence on the degradation of concrete by lactic and acetic acid; 1) cement type, 2) aggregate type, 3) addition of fly ash or silica fume, 4) addition of polymers, 5) application of cement-bound surface layer and 6) impregnation.

Reinforcement corrosion is an important degradation mechanism for floor slats of concrete material. High concentrations of carbondioxide in dairy farms may give rise to carbonation of concrete slats. In general the risk of chloride initiated corrosion in floors is higher than the risk of carbonation initiated corrosion because of the high chloride content found in floors of farm buildings [13]. The high chloride content may arise from manure and feed residues and sometimes from accelerators used in the concrete.

Mechanical wear occurs on floors in animal houses. Because of the mechanical wear the floors of animal houses may become too slippery, which may result in paw disorders. It has been suggested a concrete floor with a regular hexagonal pattern in order to improve the slippery safety [16].
3.2 Wall Structures
Farm buildings are mostly designed as industrial buildings with structural systems of stone, brick, timber or steel material. Structural systems of stone or brick in old farm buildings are covered on the inside and outside by painted plaster systems. The structural systems of timber and steel are usually covered by wood fibre and hardened gypsum boards or steel sheets, when new buildings are designed.

The equipment inside animal houses often consists of steel, zinc and aluminium structures combined with wood fibre and cement based boards. The equipment is often made of bad quality because it will rather often be changed depending on the animal production.

Wall structures of manure and silage storages are mostly made of concrete material. Especially wall structures for silage storage structures are often painted on the inside as environmental protection.

Degradation

Field studies of corrosion in houses for fattening pigs have shown severe attacks on the lower parts of the equipment (Figure 1). The massloss has been measured to 200 and 50 μm/year for steel and zinc structures respectively. Corrosion attack on aluminium structures are very severe in pig houses on those points where manure and feed have gathered. The attacks are not spread evenly over the material surface but are concentrated on special points [17].

![Figure 1. Example of building components in pens for fattening pigs with high risk of corrosion [17].](image)

Micro biological corrosion may occur in agricultural environment. Such corrosion occur under anaerobic circumstances and neutral pH-values. The cause is mainly sulphate reducing microbes. Steel structures for covering manure tanks have been exposed to this type of corrosion [18].

Timber walls in farm buildings are protected against biological degradation by constructive design and by applying chemical preservatives. The recommendation is to design against degradation before using wood treated with chemicals.

Fungi are the biological degradation that cause most damages in farm buildings. It is the decay producing fungi that are worst because they reduce the strength by removing lignin and cellulose [19].
3.3 Roof Structures

Today steel compete hard with timber as a structural material for roof structures of farm buildings. Principally the roof construction consists of either beams supported by hinged or fixed posts or rafters supported by posts in combination with girders. In farm buildings post and beam timber structures range up to 25-30 m span and they can be very cost effective for spans between 7 and 20 m [19].

The ceiling constructions can be an insulated ceiling with wood-based panels or spaced boardings as cladding material. A breathing ceiling with air inlet through the insulation is comfortable when spreading the air into the pens. Insulated parallel roofs of self-supporting elements are effective to create good air volumes for the animals. Uninsulated roofs are usually made of steel sheets or glass fibre board sheets.

Degradation

Degradation of roof structures in animal houses mostly concerns the inner surface of insulated ceilings. Because of high air humidity the unpainted steel sheets corrode very fast. Unpainted steel sheets also corrode very fast on the surface faced to the outside climate. Wood-based panels often show mould on the inner surface of the ceiling.

4 Discussion

The environment in buildings and structures used in agriculture consist of many different factors. There are handled large amounts of organic material such as different feed stuff and manure, which leads to high biological activities especially inside animal houses. The micro biological activities cause creation of organic acids. Inside animal houses high humidities and varying temperatures often occurs.

Because of the aggressive physical and chemical agricultural environment building materials and components deteriorate very fast and this is very costful for the agricultural sector. This is a major problem concerning the durability of building materials and components in farm buildings.

In the future it is important to investigate the chemical and physical environment more intensively in the most exposed places of farm buildings. This knowledge can be used as a tool at choosing material and components with prolonged durability.

5 Conclusions

The agricultural environment has its main influence on floor surfaces inside farm buildings. The floor surfaces are exposed to a chemical and physical environment, which is very aggressive, because of different elements originating from manure, drinking water and feed stuff.

Floors and other building components of farm buildings show different degrees of degradation. Concrete material, which is often used in floors and walls need a high material quality to resist against the chemical and physical attacks.
6 References