Issues of Concrete in Silage Pits

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Abstract. The article briefly describes issues of concrete in silage pits. It explains the basic principle of ensiling and the process of concrete degradation due to the action of acidic silage juices on the concrete surface. Typical signs of concrete degradation after using a silage pit for one year can be seen in the photographs.

1. Introduction

One of the methods of storing livestock feed is its preservation by so called ensiling. Ensiling is a fermentation process in which the feed (maximum dry matter content 45-50%) is stored in a silage pit, while being constantly compressed (e.g. by tamping down, rolling) and it is then airtightly sealed. This method of preservation, unlike hay drying, preserves the feed (silage) in a juicy state. The preservation is carried out by lactic acid fermentation of sugars contained in the silage feed without the access of air while retaining the nutrients and vitamins. In order to maintain the highest quality of silage, a sufficient amount of lactic acid, which is the basic preservative, must be produced as soon as possible. A pH of silage is generally lower than 4. The anaerobic environment in which no rotting processes occur is due to the acidic environment, the restriction of air access and the production of CO₂ produced by food respiration and microbial activity. Failure to comply with the technological discipline of silage preparation or the use of unsuitable fodder cause aerobic degradation - rot. This degradation destroys silage by biochemical processes with access of air. This process produces butyric, acetic or formic acids which make silage unusable (in addition, it contributes to the concrete degradation) [1, 2].

2. Methods of ensiling

Silage troughs or silage troughs are most commonly used for silage in the Czech Republic, varying considerably from both the capacitive and the structural aspects. In terms of construction, pits can be divided into passable and impassable, aboveground, half-recessed and fully recessed, monolithic and prefabricated. The most common material for the construction of pit walls is concrete. Concrete or asphalt concrete are also used for the floor. After filling the trough with silage (maize, fodder crops, sunflower, etc.) and with admixture of additives (acids based additives and their salts, additives containing a source of sugar, probiotic additives etc.), the silage is properly compressed (using tractors, rollers) in order to force the air out. The silage surface is covered with a special tarp that is weighted down (usually with old tires). The cover is to prevent access of air and rainwater to silage. Other less usual methods of ensiling in the Czech Republic are: silage towers and silage put into bags or bales [1, 2].

Silage troughs in the Czech Republic are most often made out of monolithic or prefabricated reinforced concrete with a rectangular floor plan. The side length is 30-100 m, the side width is 15-30 m, and the wall height is 1.5-6 m. The wall thickness is usually 150 to 250 mm. The reinforced
The concrete floor has a thickness of 150-300 mm and is generally divided into units with a side length of 4-6 m, whereas the whole area is sloped in the direction of the entrance with a gradient of at least 1%, preferably 2%. The minimum compressive strength of the concrete class with respect to XC4 and XA3 exposure classes is C 30/37. Very often, the designer of the silage pits proposes concrete for XC4, XF4 or XA3 exposure classes. According to CSN EN 206 and CSN P 74 2304 the minimum requirements for C30/37 concrete of the above classes are the following [3 and 4]:

- maximum water coefficient \( w = 0.45 \)
- minimum cement content = 360 kg/m\(^3\)
- minimum air content = 4%
- maximum pressure water seepage depth = 20 mm

### 3. Chemical action of silage juices on concrete

Silage juices are organic acids consisting mainly of lactic acid (butyric, acetic or formic acids are formed during inappropriate ensilage). The volume and acidity of juices fluctuates during fermentation and depends on the type of feed stored and its moisture content at the beginning of the ensilage process. The volume of silage juices further depends on the tightness of the plastic covering which prevents rainwater from flowing into silage. Rainwater leakage occurs especially along the walls. It is proven that the pH of silage juices ranges from 2.5-4. Due to the action of these very acidic juices, degradation of the surface layer of concrete occurs in a very short time (even after one year of use). The initial damage to the concrete is usually local, in places where acidic juice concentration usually occurs, usually into depths of 1-5 mm. Cement putty on the surface of concrete walls and the floor is broken down into non-cohesive grains and coarse aggregate grains are exposed.

The low resistance of concrete to the acidic environment of silage juices is due to its high alkalinity (the pH of young concrete is higher than 13). The reaction of acidic juices with cement hydration products causes type II corrosion. Type II corrosion takes place when solutions penetrating into the capillary pore structure of concrete react with the cement matrix which results in the formation of easily soluble compounds. The cement matrix is gradually degraded, losing its binding properties and ultimately reducing the mechanical properties of the concrete. In the initial phase, the portlandite \( \text{Ca(OH)}_2 \) is “attacked” first and subsequently the decomposition of the other components of the cement putty takes place, i.e. calcium hydrosilicates and hydroaluminates, while calcium salts are formed. The rate of concrete degradation depends on the solubility of these calcium salts and on the behaviour of the formed corrosion products layer. The more soluble the reaction products are and the faster they are washed out of the concrete, the faster the degradation process takes place. The speed of corrosion processes is dependent on whether the reaction products adhere to the surface of the concrete or are washed away. When adhering to the surface of the concrete, the reaction products help to slow down the access of acidic juices. During the silage removal, the mechanical action of the collection attachment of the loader rubs against the concrete wall and floor and thus accelerates the action of acids on the newly opened surface of cement putty [5, 6].

Effect of lactic acid on concrete can be described, for example, as follows:

\[
\text{Ca(OH)}_2 + 2\text{C}_2\text{H}_4\text{d(OH)COOH} + 3\text{H}_2\text{O} \rightarrow \text{Ca}[^2\text{C}_2\text{H}_4\text{d(OH)COO}] \cdot 5\text{H}_2\text{O}
\]  

Effect of acetic acid on concrete can be described, for example, as follows:

\[
\text{Ca(OH)}_2 + 2\text{CH}_3\text{COOH} \rightarrow \text{Ca(CHOOC)} \cdot \text{H}_2\text{O} + \text{H}_2\text{O}
\]  

The usual method of protecting concrete against direct exposure to acidic environments is so-called secondary protection of concrete by coatings with organic substances (e.g. epoxy or polyurethane coatings). They guarantee long-term service life only in the case of a sufficient thickness (usually greater than 500 \( \mu \)m) and complex compactness. In the case of defects in the coating, the coating quickly becomes corroded and almost immediately delaminated. As a result, there is a significant
reduction in the protection of the concrete structure. Defects in protective coatings on concrete components are frequent and are closely related to the quality of the technological application and implementation. This secondary protection also has very little resistance to additional mechanical damage.

4. Examples of concrete degradation of a silage pit
The following photos show the effects of acidic silage juices on concrete after only one year of use of two silage pits. The first silage pit ‘figure 1’ was made by a monolithic method from concrete C 30/37 XC4, XF4, XA3, S4 Dmax 22. The wall thickness is 200 mm and the height 5.5 m. The second silage pit was made from prefabricated panels ‘figure 5’ made of C 35/45 concrete XC4, XF4, XA3, S3 Dmax 22. The wall thickness is 150 mm and the height is 6 m. A coating was applied to the surface of the walls of both silage pits to provide secondary concrete protection. On the basis of a visual inspection of silage pits carried out after one year of use, it can be stated that the secondary protective coating failed in both structures and local concrete degradation due to acidic juices occurred in depth of about 5 mm ‘figure 2 and 3’. In some places, coarse aggregate grains were exposed ‘Figure 4 and 7’. Concrete degradation occurred especially in the area of wall footings and also in the wall area, especially up to a height of about 1.5 m ‘figure 6’. An objectively effective method of protecting concrete structures against acids in full cross-section is to modify the used cement or concrete mix with suitable organomer components. Epoxy-based organomer components, copolymers based on acrylic acetate, or even specific acid-resistant polyethers can be used successfully. These groups differ significantly in binding properties with the C-S-H gel (if need be with the aggregate surface), the ability to fill in the pores, the effect they have on the mechanical properties of the concrete, their own resistance to acids (e.g. silage juice) and other aggressive substances such as petroleum products. However, not every such substance is suitable for application to a strongly alkaline environment of cement concrete.

Figure 1. View of partially removed silage and surface damage of a monolithic concrete wall.

Figure 2. Small blisters in coating with degraded cement putty, depth max. 5 mm.
Figure 3. Small blisters and cracks in coating with degraded cement putty, depth max. 2 mm.

Figure 4. Exposed rough aggregate of the floor around the drainage channel.

Figure 5. Prefabricated panels with a non-resistant coating with a noticeable concrete degradation process along its height.

Figure 6. A degraded prefabricated panel footing to a depth of approx. 5 mm. There are obvious traces of the collection attachment of the loader on the panel - indicated by a red arrow.

Figure 7. Detail of the degraded surface of the panel with exposed coarse aggregate grains.
5. Conclusion

From the above mentioned facts and illustrative examples of two silage pits, it is obvious that despite the type of concrete designed for the highest exposure class (XC4, XF4, XA3) the acidic silage juices cause relatively rapid degradation (decomposition of cement putty) of the concrete surface layer. In addition, in these cases an inappropriate coating was used that failed to provide secondary protection of the concrete. The highest degree of chemical attack of XA3 exposure class is intended for an environment with a $\text{pH} \geq 4$, whereas the silage juice environment is more aggressive, the $\text{pH}$ is usually 3-4. In addition to complying with the principles and requirements set out in CSN EN 206, secondary protection using organic acid-resistant coatings with a $\text{pH}$ of 2.5-4 must be used to ensure the long-term service life of silage pits. Another option is the development of new concrete with exceptional resistance to aggressive substances. The aim of further research is to develop concrete with high tightness, compactness and resistance to aggressive substances throughout the cross-section of the structural element created by the application of polymer nanoparticle material directly to the concrete mix. The concrete thus created will not need to be provided with secondary protection and the concrete surface itself will be highly resistant to mechanical damage that the coatings used so far are poorly resistant to.

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