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Basic Characteristics of an Appropriate Waste Fillers for Solvent Free and Water-Borne Industrial Polymer Floors and Their Utilization

Jana Kosikova

Brno University of Technology, Faculty of Civil Engineering, Institute of Technology of Building Materials and Components, Veveří 331/95 602 00 Brno, Czech Republic

Abstract: Recently the manufacture of epoxy coating and flooring materials begun to be under strong pressure to use more environmentally friendly raw materials in its composition. First tendency to reduce of solvents and diluents contained in the materials appeared at the end of 90 ́s. This situation was supported by the Council of Europe in 2004 to reduce VOC emissions to zero till 2020. Solvent materials were thus largely replaced by solvent free materials from which the volatile substances are not released into the air. But pressure continued to increase, and over the past decade began to take centre stage water-based epoxy. On the Czech market solvent based material is still occasionally used, but predominant are solvent free materials. There are no commonly used materials containing wastes as fillers in new water-borne and solvent-free epoxy materials. Characteristics identification of the waste material as a potential filler is a set of properties that determine the limits of secondary raw materials or waste as a filler. This paper describes the basic characteristics which must be selected to meet the requirements, to affect negatively the workability, sedimentation, properties and behavior of the final floor system. Some materials must comply with special requirements, such as resistance to chemicals, etc. Next part of paper talks about utilization of polymer floors and their mechanical properties.

Key word: Industrial polymer flooring materials, waster fillers, building materials.

1. Introduction

Materials on polymer basis are the most commonly used systems of industrial flooring at present. They are employed both within the construction and in reconstruction and repair works and may fulfil not only protective and technical functions, but also the aesthetic one. They consist of several layers which are interconnected (usually impregnation, smoothing compound, final coat) and which together resist to external effects acting on them.

Industrial production increases and similarly the amount of generated industrial waste material increases; as a consequence, it is necessary to employ these in order to prevent their landfill and negative impact on the environment. The use of waste materials has also a positive effect on saving natural resources whose reserves are steadily decreasing. Finally, the positive economic impact of such action may be considered. For a producer the cost of providing the waste to a consumer is lower than depositing it in a landfill. Also for a consumer the cost of industrial waste material is lower than that of a primary natural raw material. This should result in reducing the building products ́ final prices and, consequently, to an increased competitiveness of building products manufacturers in the field of their professional competence.

Given the increased emphasis on ecological thinking and behavior, great pressure began to be put on environmentally friendlier raw materials used in the manufacture of epoxy coating and flooring materials. The tendency to reduce solvents and diluents contained

Corresponding author: Jana Kosikova, Ph.D., research fields: civil engineering.

in protective compositions was supported by a decision of Council of Europe 2004 on the VOC reduction to zero. Solvent materials were therefore largely replaced by solvent free materials and over the last ten years, water-based epoxy materials began to take center stage. Since the development of these materials is an ongoing process, the research and verification of options concerning the use of waste materials as fillers continue along with it. Important indicators for using recycled materials as fillers are their properties which are subject to high requirements.

2. Industrial Floors

Polymer flooring systems are composed of several layers that are usually applied to the final wear layer of industrial or residential floors. They are often realized as a new final surface layer in the manufacturing warehouses, in food, pharmaceutical and automotive industry, in laboratories, hospitals and shopping centres. They are also widely used in the reconstruction and rehabilitation of damaged floors.

As they show excellent physical and mechanical properties, they may even constitute the final surface of trafficable roofs. They are flexible, waterproof and resistant to exposure to chemicals, solvents and petroleum products. They are easy to clean, hygienic and resistant even to aggressive cleaning agents and UV radiation.

Another big advantage of these multi-layer polymer floors is their aesthetic effect which is mainly due to the possibility to realize them in a wide colour range.

Synthetic floors may thus be realized, through the use of fillers and pigments of coloured silica sand or various surface-applied colour chips, in colour limitless versions [1].

As shown in Figure 2, it is possible to interleave them with light chains and similar design elements.

These materials contain liquid component – binder and a loose component – fillers, as well as other materials such as hardener, pigments, colour chips, etc. The liquid synthetic binder component is usually mixed with natural or coloured artificial fillers before application. Thickness

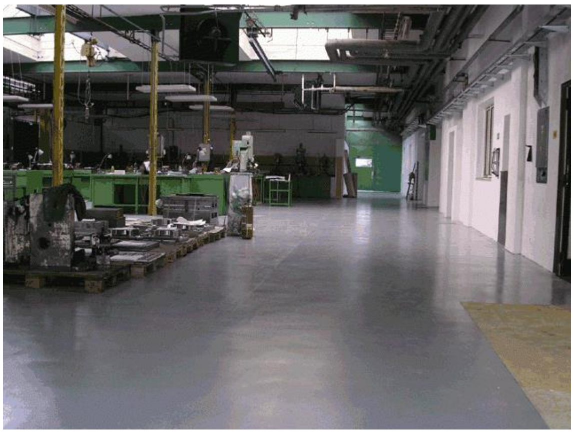

Fig. 1 Example of an industrial floor applied in a production hall [1].

Fig. 2 Entrance to the web portal „Seznam" headquarters [2].

of the multilayer polymer systems is mainly dependent on the desired load and service life of the floor and is ranging from 0.15 mm (coating) to 5 mm (smoothing compound). According to user ́s requirements, its surface may be smooth to rough in compliance with the required coefficient of friction [1].

Polymer flooring systems are usually realized as compound flooring systems: the surface is first treated with bonding primer and then self-levelling smoothing compound and a last finishing coat are set. The manufacturer may specify thickness and number of layers according to customer's technical requirements. All these materials are mostly based on synthetic resins.

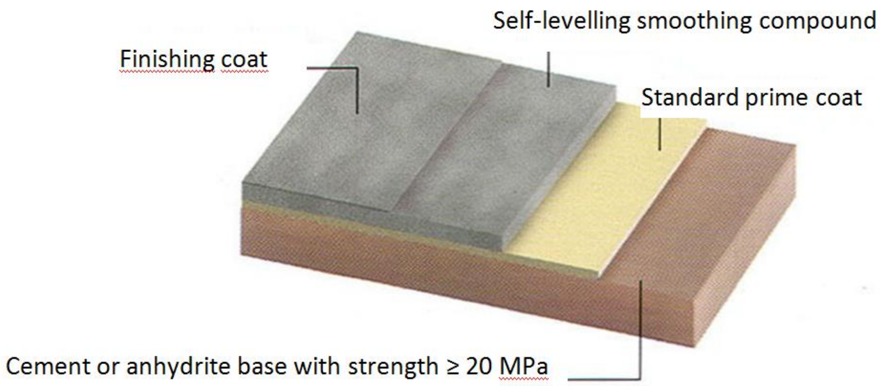

Fig. 3 Multilayer polymer flooring system structure [3].

3. Composition of the Protective Surface Materials based on Polymers

Most protective coatings are used as floor systems, primers, protective coatings, etc. Production of these materials is commonly industrial. They are composed of several components and therefore can be regarded as composite materials. The main components are binders and fillers, pigments and other ingredients.

a. Binder - currently the most commonly used primarily epoxy and polyurethane materials as solvent free (with only a low solvent content in fact) or the recently preferred water-based systems.

b. Fillers - the mentioned materials are filled in the range of 20-45% of their volume. Fillers are designed to reduce the need of binders and thus to reduce the product cost. Some filler can even improve the properties of produced materials. Ground limestone or chalk, as well as talc, diatomaceous earth, ground quartz, etc. are commonly used. Nevertheless, the most frequently used is fine silica sand. Due to the tightening supplies of natural resources and at the same time to the existence of large quantities of wastes, we are looking for new ways how to take advantage of wastes and how to replace with the natural filling components used so far.

The choice of materials usable as fillers is limited by certain already-known characteristics and limits. It primarily concerns a chemical incompatibility between fillers and the component ́s base matrix.

Silicone-based materials are one of the examples. Fillers have to be completely inert in relation to the whole system.

They must not be engaged in the process of polymerization and must equally not accelerate or inhibit this process. They must not lead to the extraction of components from the filler system. Other conditions for the use of waste material as fillers for protective coatings are:

- Specific gravity of fillers - it must be higher than the specific weight of the connective base, but must not be significantly higher, to avoid sedimentation.
- Shape and size of particles - these have a major impact not only on sedimentation, but also on many other key properties.
- Flammability of construction materials - an indicator of how building materials contribute to fire intensity.
- Adhesion - adhesion between fillers and binder has a significant effect for all types of composites.

Main physical parameters of the new material are defined by the chosen fillers. Besides their properties, the cost is another major aspect in the choice of particular fillers. Lower cost consequently permits to decrease the price of the final product.

c. Pigments - mainly stable inorganic pigments are being used, both natural and synthetic.

d. Excipients - especially dispersant additives to facilitate dispersion of pigments and fillers, additives regulating the workability, preservatives, hydrophobic additives, etc.

Industrial protective materials are a well-balanced combination of all components, to achieve optimum workability as well as optimum physical and mechanical properties [4-6].

4. Essential Requested Characteristics of a Suitable Filler

4.1 Pollution of Filler Material

It is necessary that filler does not extract nor add components from or into the system - particularly in the case of volatile substances and their potential impact on health and environment. The extracted substances may adversely affect the polymerization of the system. They may act as plasticizer or dye system and may thus be causing surface defects, etc.

Another negative effect of pollution may be bad adhesion of filler particles to the binder due to repulsion. Today it is possible to effectively and efficiently control the surface adhesion by 100%. But pollution, especially in waste and secondary raw materials may be of unstable amount and quality. In such a case, this may be a risk factor.

For a correct choice of filler material, it is always good to know at least the approximate composition of the system and the ability to track any potential deviations.

4.2 Specific Gravity

Specific gravity of fillers is related to that of binder. It must be higher than the specific gravity of the connective base but must not be significantly higher. Currently used fillers have this specific gravity (Tab. 1):

The reason for a careful selection of filler in terms of its specific gravity is the following: it has to have a specific weight so that the filler material would be equally dispersed in binder.

This provided, the filler will not have a tendency to settle down significantly in a short term (in weeks), nor will it have a tendency to come up to the surface of the connective base.

Table 1 Specific gravity of currently used fillers.

Type of filler	Specific gravity [g/cm3]
graphite	2.1
corundum	4.0-4.1
silica	2.6
calcite	2.7

Besides the specific weight of particles, sedimentation is also significantly affected by the particle shape and size and by viscosity of the dispersion medium. With increasing viscosity the dispersion medium slows down the process of sedimentation.

4.3 Granulometry, Particle Size

The most important features that are affected by particle size and shape are:

Sedimentation - the way in which the filler would sediment should be considered carefully, in order to be able to predict its usability in the polymer base. During sedimentation, the material is divided into various fractions according to the particle size, since the sedimentation rate of particles with large radius is greater than the sedimentation rate of particles with smaller radius.

The motion of a particle is affected by frictional force – Ffrict, by gravitational force - Fgrav and by lifting force Flift, as shown in Fig. 4:

Assuming we have a spherical shape of particles, sedimentation rate in the liquid can be expressed using this equation:

$$\mu = \frac{2}{9} \cdot \left(\frac{\rho - \rho_k}{\eta_k}\right) \cdot r^2 \cdot g$$

Where μ is the sedimentation velocity [m/s], ρ is the specific weight of particles [kg/m3], ρk is the liquid ́s specific gravity [kg/m3], ηk is the liquid ́s viscosity [Pa.s], r is the particle radius [m], g is the theoretical mean value of gravitational acceleration on Earth's surface, and is considered 9,823 m/s2. The relationship also implies that the concentration of particles is low and they are not in interactions [7-10].

This relationship is suitable for the first estimate of sedimentation rate in the liquid. It is always necessary to experimentally verify the calculation.

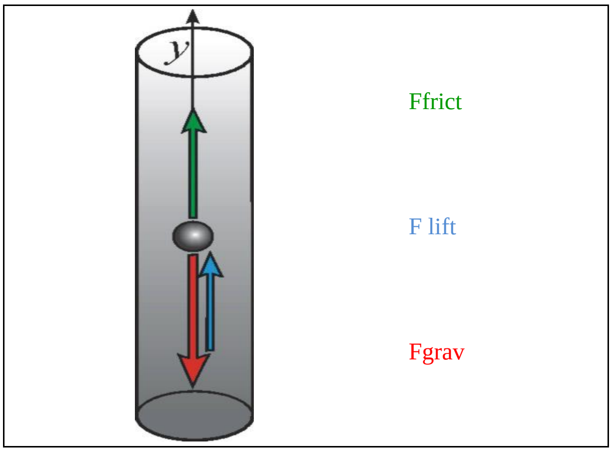

Fig. 4 The forces affecting the motion of a particle.

Application properties – the particle shape and size have a significant impact on application properties of the resulting system. Improperly selected shape, size or granule aspect ratio can affect both aesthetic and functional properties of the epoxy system. It is always necessary that distribution curve contained both - finer as well as coarser fractions. Their ratio then depends on the specific application requirements. Mono-fraction filler system makes good application properties.

The rough parts of filler provide easier application and a possibility to cast the mixture (cast the industrial floor), whereas the smoother shares provide a certain degree of thixotropy and they slow down sedimentation of coarser units.

To properly set a correct distribution curve is a matter of theoretical training, but especially it is a question of experimental tests. Various fillers may have the same distribution curve of the system and at the same time a completely different behavior. Also a different type of application or a varying final thickness requires a different approach.

4.4 Flammability

Flammability of construction materials is an indicator of how building materials contribute to fire intensity. According to a standard ČSN 73 0862, building materials are divided into 5 degrees of flammability:

A - non-flammable building materials

B - no easily flammable building materials

C1 - hardly flammable building materials

C2 - medium flammable construction materials

C3 - easily flammable building materials.

Czech standard ČSN 73 0810 specifies a new way to classify substances by 5 degrees A1, A2, B, C, D, E, F. Table 2 describes flammability grade levels in relation to reaction to fire.

Czech standards ČSN 73 0810 and ČSN EN 13 501-1 apply a term "flame spread index" for classification of flammability in following values:

A1fl, Afl → *is* = 0 [mm/min]

Bfl→ *is* in range 0 ≤ 50 [mm/min]

Cfl→ *is* in range 50 ≤ 100 [mm/min]

Dfl až Ffl → *is* more than 100 [mm/min]

Fillers should not have worse parameters than the epoxy matrix. Table 3 shows the required values of the above mentioned parameters for fillers used in polymer protective coatings.

4.5 Adhesion

In general, the influence of adhesion is more important in particulate composites than in fiber composites. There is a high amount of surface adhesion modifiers on the market and their usage need is low (most frequently about 2 wt. %). The use of modifiers can affect adhesion properties of composites in the range of 100%.

Table 2 Flammability grade levels in relation to reaction to fire.

Flammability grade	Reaction to fire
A	A1
B	A2
C1	B, C
C2	D
C3	E, F

Table 3 Required values of aggregate.

Parameter	Required value
Flammability	A, B
Flame spread index	Max. 50 mm.min-1
Reaction to fire	A1, A2, B

4.6 Availability and Sustainability of Waste Fillers

Availability and sustainability are essential criteria for the selection of filler. Availability is a criterion that can be evaluated rather easily. It depends on the distance, on the price, etc.

Long-term nature of material is related to the sufficient amount of secondary raw materials.

It is important to know whether the supply of these materials (their reserves) is not limited to a short period of time or whether the materials are not significantly depleted by production. They should also not damage the environment, as this could possibly result in a decrease of their production.

Another criterion is a long-term usage. From this perspective, waste material from glass screen is not much interesting, as it will be available for a relatively limited period of time. The reason is the massive replacement of the classic TV screen by plasma or by LCD TVs. On the contrary, a long-standing source comprises a possibility of usage for at least 5-10 years from the completion of the relevant development.

4.7 Stabile Quality and Composition of Fillers

A very important criterion for selection of secondary material/waste as filler is its composition stability.

In this type of protective materials, it is necessary to take into account a certain degree of instability: it is a multiple component composition of different particle size and shape and chemical properties. The range of selected parameters should be guaranteed by the producer of waste in order to avoid constant need for changing formulas according to variable or differing parameters of fillers.

4.8 Mechanical Parameters of Fillers

The compressive strength of the filler material should be at least equal to the compressive strength of epoxy layers. If the compressive strength of the filler was significantly lower, it would lead to degradation by mechanical loading and thus to destruction and failure of the flooring system.

The compressive strength of standard epoxy material ranges 50-60 MPa. The compressive strength of standard concrete constructions is about 20 MPa. It is always necessary that the thickness of the floor corresponded not only with the expected mechanical stress, but also with a load capacity of the concrete to prevent destruction of the concrete slab floor just by standard using.

5. The Use of Polymer Floors Filled with Waste Materials

Polymer industrial floors filled with waste materials are applicable fully and to the same extent as materials filled with conventional fillers. These floors have found their place both in interiors and exteriors, where much of it serves as walkable or trafficable space, especially car parking places.

As the polymer floors are easy to clean, they are used in factories, offices and households as well. Materials with improved chemical resistance are extensively used in laboratories or chemical industry manufacturing plants.

6. Conclusion

This paper describes main and most important properties of fillers used in polymer matrix. These properties are important both for commonly used natural materials and for waste materials. Correct choice of filler affects resulting properties of the whole polymer system containing binder, filler, pigments and other excipients. Resulting properties can vary in all range; pollution of filler material, specific gravity, granulometry, strength, adhesion and sedimentation of fillers are essential. Other mentioned, as flammability, availability and sustainability, etc. Are also important, but they are not so significant.

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