

Environmental Limits of Using Newly Developed Progressive Polymer Protection and Repair Systems

J. Hodna, B. Dohnalkova, V. Petranek, R. Drochytka

Abstract—The paper is focused on the identification of limiting environmental factors of individual industrial floors on which newly developed polymer protection and repair systems with the use of secondary raw materials will be used. These mainly include floors with extreme stresses and special requirements for materials used. In relation to the environment of a particular industrial floor, it is necessary to ensure, for example, chemical stability, resistance to higher temperatures, resistance to higher mechanical stress, etc. for developed materials, which is reflected in the demands for the developed material systems. The paper describes individual environments and, in relation to them, also requirements for individual components of the developed materials and for the developed materials as a whole.

Keywords—Limits, environment, polymer, industrial floors, recycling, secondary raw material, protective system.

I. INTRODUCTION

RESEARCH of new protection materials, which is now in progress at the Brno University of Technology, Faculty of Civil Engineering, Institute of Technology of Building Materials and Components, deals with the development of progressive polymer materials with the use of secondary raw materials as a filler. These environmentally friendly and also economically advantageous materials will be usable as protection and repair systems on industrial and other floors. [1]

As concrete or other surfaces on mineral basis do not create a resistant, let alone comfortable environment, they are often provided with surface finishes based on polymers which ensure their sufficient resistance against workload and external effects. [1]

Such surfaces have a high mechanical resistance to pressures, abrasions, impacts and, in general, they increase the resistance of structures against mechanical loads. They feature high durability even at increased temperatures or exposure to chemical environments such as oils, oil products, acids, caustics, solvents and various detergents. Polymer protection systems have an excellent adhesion to various types of substrates such as fresh concrete, metal or wood. Their great advantages include easy applicability and quick

commissioning of such structures.

The basic condition for the correct pointing of the research is identification of limiting factors of environments in which these materials should be used. Based on such information, it will be further possible to correctly specify properties which these materials should meet. [2]

The limiting factors were divided by the environment which will act on the developed materials during exploitation, on the application conditions, and also by the types of the states of substrates on which the developed materials will be applied.

The identification of limiting factors also affects the subsequent selection of raw materials utilized for the development of new materials such as binders but, in some cases, also fillers of these composite materials.

The reason for the extensive identification of limiting environmental factors is the aim to design individual types of materials covering almost the entire range of possible requirements for surface materials.

II. IDENTIFICATION OF LIMITING ENVIRONMENTAL FACTORS

A. Factors Influenced by the Types of Industrial Floors

One of the most substantial factors is the type of industrial floor on which the developed materials should be used. It's because the type of operation or more specifically the type of industry affects the chemical-physical environments in which the designed materials will be exploited.

The following types of industrial floors were identified by the most frequent anticipated applications:

- 1) Food industry
- 2) Chemical industry
- 3) Petrochemical industry
- 4) Mechanical engineering and building industries
- 5) Sanitary clean operations
- 6) Health service, e.g. antibacterial finishes, resistance to disinfectants
- 7) Others, e.g. antistatic finishes – production of electrical components, computer rooms, server rooms

B. Types of Application Environments

Limiting factors based on the type of industry, but they must be further specified very exactly so that the portfolio of designed materials meets almost all varied conditions.

One of the very substantial effects limiting the type of material usable for a particular application is limiting factors based on the application environment and conditions for the application of developed materials:

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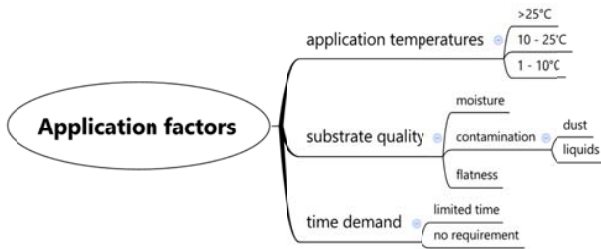


Fig. 1 Diagram of the division of application based limiting factors

C. Types of Environments of Designed Materials Exploitation

Crucial and at the same time common are effects arising from a particular environment in which the designed materials will be used. It is very important to know in details the technologies used on individual floors. It very often happens that not all alternatives of exploitation of surface materials are mentioned in the specification. For example, it is not mentioned that at regular shutdowns surface materials get in contact with a quite different environment (liquids) than in common operation. [4]

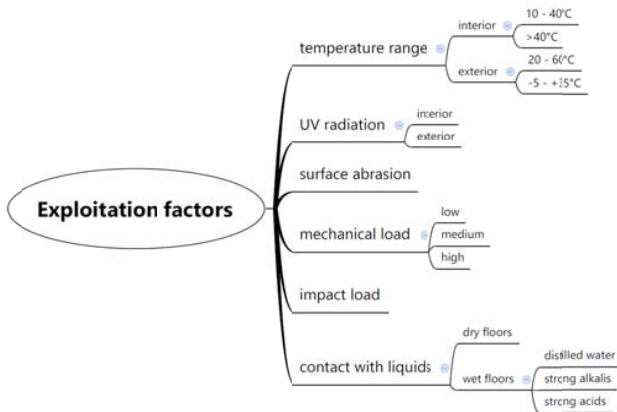


Fig. 2 Diagram of the division of exploitation based limiting factors

The knowledge of the operating and environmental conditions which will act on the repair part is essential. Operating conditions or environmental effects cause response (effect). Response may occur in various parts of the repaired part of a structure: on the surface, in the repair material, in the steel reinforcement, on the contact, as well as in the original substrate, etc. [4]

III. IDENTIFICATION OF LIMITING FACTORS IN INPUT RAW MATERIALS

The selection of input raw materials for the development of new repair materials represents an important and complex process at which it must be understood what the user expects, what the operating and environmental conditions require, but it is also necessary to take the method of application into consideration. After specifying clear requirements and defining material properties, it is possible to proceed to the selection of suitable materials. [5]

For selection, we must perfectly know all properties of raw materials and materials. Materials must feature mutual compatibility since there should be a perfect co-action of the existing and repair materials. Sometimes more than one material or also a set of materials is suitable. The final selection of raw materials and materials is carried out on the basis of the relation between the price, working characteristics and the technological demand of repair execution. [4]

IV. REQUIREMENTS FOR THE PROPERTIES OF PROTECTION AND REPAIR MATERIALS AND THE CONSEQUENCES OF THEIR INCORRECT SELECTION

The final properties of protection and repair materials are important as early as the selection of suitable materials for the repair to be of high quality. These properties can be divided to three groups.

A. Load Capacity Requirements

The basic requirements for load capacity can include, in particular, a sufficient adhesion to the substrate and cohesion of the material alone, low volume changes, minimum shape deformation at load and minimum shrinkage during the material curing. The material used for reconstructions and repairs should have a comparable modulus of elasticity to the original surface. [4]

If any of the requirements are not met, there is a risk of consequences summarized in Table I.

TABLE I
LOAD CAPACITY REQUIREMENTS

Function requirements	Key material properties	Consequences of incorrect selection of material
Cohesion with substrate	Sufficient adhesion to substrate and cohesion of material alone	Low cohesion with substrate, separation of repair materials from substrate
	Low volume changes	Cracks in repair materials, their separation from substrate
Load capacity required by structural engineer	Modulus of elasticity comparable to original material	In the case of significantly different modulus of elasticity, load is not transferred as expected, either the original or repair material is overloaded.
	Minimum shape deformation at load	Load causes inadequate shape deformation of repair materials, which leads to overloading of the original materials.
	Minimum shrinkage during material curing	Occurrences of cracks, stress in the repair material-substrate contact; due to shrinkage the ability of repair materials to transfer load is reduced.

B. Requirements for Properties in Relation to the Operating and Environmental Conditions

The developed protection material should have the same or maximally a similar coefficient of thermal expansion, high water-tightness of the system should be ensured, as well as a suitable distribution of air pores and low material permeability. Due to its application in the chemical, food and health industries, the material should be resistant to the action of aggressive gases and chemicals. Also, a high resistance to the action of ultraviolet radiation and abrasion is necessary, high tensile strength at bend and pressure, high cohesion of the

system or adhesion of the finish to the substrate and resistance to abrasion and wear. [4]

Also in this case there is a risk of consequences that can lead to damage of the material if these requirements are not met. For example, volume changes caused by temperature variations can be the cause of cracks or stresses can be generated in the contact of the repair materials with the substrate. The most frequent consequence of low water-tightness of the system is distortion of the material structure, impairment of mechanical properties or its degradation in extreme cases. The material may also corrode by the action of aggressive substances and chemicals.

TABLE II

REQUIRED PROPERTIES IN RELATION TO THE CONDITIONS OF OPERATION AND ENVIRONMENT, EXTERNAL LOADS AND DURABILITY

Function requirements	Key material properties	Consequences of incorrect selection of material
Cyclical temperature variations	Maximally similar coefficient of thermal expansion	Volume changes caused by temperature variations may be the cause of cracks or stresses can be generated at the contact of the repair material with the substrate
Synergic action of moisture and frost	High water-tightness of the system, suitable distribution of air pores.	The consequence is distortion of material structure, impairment of mechanical properties or its degradation in extreme cases.
Action of aggressive atmospheric substances	Low material permeability (factor μ), high compactness. High resistance of the material to aggressive gases	Degradation of the material matrix, impairment of strength characteristics, development of reinforcement corrosion
Action of chemicals from the external environment	Low material permeability (factor μ), high compactness. High resistance of the material to chemicals	Degradation of the material matrix, impairment of strength characteristics, development of reinforcement corrosion
Action of UV radiation	High resistance to ultraviolet radiation	Changes in the mechanical properties of the material. Typically, changes in the modulus of elasticity. Materials become "brittle"
Flowing or migrating liquids	High material compactness, abrasion resistance of material	Erosion ("wash-out") of the structure surface. The action of flowing liquids stresses the exposed surface by abrasion
Vehicle travel	High tensile strength at bend and pressure, high cohesion of the system. Abrasion or wear resistance.	Loss of cohesion of surface finishes. Concrete crumbling near edges, etc.
Impacts	High strength characteristics, relatively lower modulus of elasticity, high system cohesion	Material destruction, loss of cohesion of surface finishes.

C. Requirements for Technological Intensity and Appearance Properties

Due to comfortable technological production and application processes, the materials must have a good growth of initial strengths, a suitable consistency or workability and low volume changes during curing.

When using the materials, it is necessary to monitor the method of their storage in compliance with the manufacturer's

instructions (usually provided on the package and in the material data sheet) and to process them before their guarantee period elapses. It is recommended to store most of the materials in dry places at a temperature of 5 to 20°C, preferably in original undamaged containers. [3]

After mixing the components, they must be applied on the structure under repair without delay. The so-called open period, i.e. the period from their preparation to the start of curing is different for various types of repair materials and, to large extent, it is dependent on the environmental parameters, particularly temperature. After this period elapses, curing materials cannot be "reactivated" any more, for example, by adding water. [6]

V. SUMMARY OF THE REQUIREMENTS FOR THE PROPERTIES OF PROTECTION AND REPAIR MATERIALS

According to the above mentioned it is evident that the materials must meet certain properties which are ensured in the system by the appropriate application of individual components of the system. The requirements placed on protection and repair materials can be summarized particularly by the most important:

- 1) High cohesion with substrate,
- 2) Good water-tightness, i.e. low absorption capacity,
- 3) Frost resistance at the T100 level or higher depending on the specific conditions of exposure,
- 4) Minimum volume changes caused by humidity and temperature variations,
- 5) Reduced occurrence of contraction cracks,
- 6) Modulus of elasticity which should be:
 - i. lower than the modulus of elasticity of the sub-concrete if the repair material does not have static function,
 - ii. the same as the modulus of elasticity of the sub-concrete if the repair material has static function,
- 7) Compression strength or tensile strength at bend at equal or slightly higher level than the sub-concrete if the repair material has static function,
- 8) resistance to aggressive fluids depending on the specific conditions of exposure.[4]

By failure to meet any of the above-mentioned properties of protection and repair systems, their life and dependability are reduced.

Quantitative requirements for these parameters are shown in Table III.

TABLE III
REQUIRED BASIC PARAMETERS OF PROTECTION AND REPAIR MATERIAL ACC. TO ČSN EN 1504-3 [3]

Parameter	Materials without static function		Repair materials with static function	
	Class R1	Class R2	Class R3	Class R4
Compression strength (ČSN EN 12109)	≥ 10 MPa	≥ 15 MPa	≥ 25 MPa	≥ 45 MPa
Content of chloride ions (ČSN EN 1015-17 or ČSN EN 14629)	≤ 0.05%	≤ 0.05%	≤ 0.05%	≤ 0.05%
Cohesion ¹ (ČSN EN 1542)	≥ 0.8 MPa	≥ 0.8 MPa	≥ 1.5 MPa	≥ 2.0 MPa
Linked shrinkage/expansion ^{1,2} – cohesion after testing (ČSN EN 12617-4)	No requirements	≥ 0.8 MPa	≥ 1.5 MPa	≥ 2.0 MPa
Modulus of elasticity (ČSN EN 13412 or ČSN EN ISO 6784)	No requirements	No requirements	≥ 15 GPa	≥ 20 GPa
Carbonation resistance (ČSN EN 13295)	No requirements	No requirements	$d_k \leq$ check concrete (MC(0.45))	$d_k \leq$ check concrete (MC(0.45))
Thermal compatibility ^{1,2}				
freezing and thawing – cohesion after 50 cycles	Visual check	≥ 0.8 MPa	≥ 1.5 MPa	≥ 2.0 MPa
ram spraying – cohesion after 30 cycles	Visual check	≥ 0.8 MPa	≥ 1.5 MPa	≥ 2.0 MPa
dry cycling – cohesion after 30 cycles (ČSN 13687-1 to 5)	Visual check	≥ 0.8 MPa	≥ 1.5 MPa	≥ 2.0 MPa

¹ The stated value is a mean value and individual values must not be lower than 75% of the stated requirement.

² The maximum allowable crack width is ≤ 0.05 mm, without delamination.

VI. CONCLUSION

The aim of this paper was to carry out an identification of limiting factors which may have an influence on newly developed systems, because the knowledge of the conditions of operation and environment which will act on the repaired part is essential for the development of new protection and repair materials. For this purpose, the first step was defining various environmental factors. Based on these information sources, typical representatives of various industrial floors were defined and described and an estimation was made regarding the types of environments to which the materials developed within this project can be exposed. The limiting factors were divided by the environments which will act on the developed materials during exploitation and the application conditions, and also by the types of the states of substrates on which the developed materials will be applied.

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