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# RESISTANCE OF VARIOUS MATERIALS AND COATINGS USED IN WOOD CONSTRUCTIONS TO GROWTH OF MICROORGANISMS

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## ABSTRACT

This contribution deals with the resistance of various materials and coatings used in wood constructions to mould growth and in the case of wood and varnishes also to bacterial growth. For testing the resistance to mould growth, the standard EN 14119, method A2 (without agar medium) and method B1 (with agar medium) were used. Tests were performed with *Aspergillus niger, Chaetomium globosum, Penicillium funiculosum, Gliocladium virens* and *Paecilomyces variotii*. Resistance to bacterial growth was tested according to the standard JIS Z 2801 with bacteria *Staphylococcus aureus* and *Escherichia coli*. Most of materials tested without agar medium were resistant to mould growth. However, the addition of the agar medium (simulation of real conditions; high dampness and presence of nourishment) predictably caused worse results. Cement bonded particleboard, extruded polystyrene and water-borne varnish were very resistant to moulds. Moreover, the water-borne varnish showed a heavy resistance to microbial growth, while a two solvent-borne polyurethane varnish showed no resistance to microorganisms.

KEYWORDS: Wood constructions, varnishes, resistance to moulds, resistance to bacteria.

## INTRODUCTION

Health and safe conditions in which people live have become a modern trend. Still more and more people are interested in quality of indoor air that is influenced not only by chemical contamination but also microbial contamination from several sources. Infiltration of the outdoor air, volatile compounds from contaminated ground, and emissions from building materials are the main sources of indoor air pollution (Gebefuegi 1995). The reasons of the interest about the quality of indoor air are especially various illnesses associated with environmental conditions (Jones 1999, Sundell 2004). Allergies and Sick Building Syndrome (SBS) are examples of the most common diseases. Microorganisms in the interior are one of the most possible reason of that illnesses. Although humans are constantly exposed to bacteria and moulds, usually without suffering harm to health, in some instances inhalation of sufficient numbers of mould spores can trigger symptoms of asthma, rhinitis or bronchitis (Crook 2010, Joshi 2008). Moreover, moulds produce allergens (substances that can cause allergic reactions), irritants, and in some cases, potentially toxic substances (mycotoxins) (EPA 2012, Frederick Fung 2004, Robert 2006).

Bacteria and mould spores are carried on dust particles. People breathe them with air and that is the way how microorganisms get into human bodies. Concentration of spores in the interior could be very high in the case of an inappropriate human behaviour. Building malfunctions, an inappropriate project or realization or using inappropriate materials allow moulds to grow and multiply on the various surfaces in the interior. Insufficient ventilation and cleaning could be other reasons of contamination by moulds in buildings (Buttner 2002, Gorny and Dutkiewicz 1999, Schleibinger et al. 2004, Stetzenbach 2004).

Mould growth in buildings is influenced by nutrient, temperature, relative moisture content, pH etc. (Kumar and Verma 2010). For each mould species and temperature level there is a minimal amount of moisture needed for the mould growth. Simply, it can be said that spores under appropriate conditions (relative air moisture > 50-60% and temperature about 20°C) are able to grow very well and fast (Johansson 2005).

Except health problems associated with moulds there is also a biodegradation of buildings by moulds. These are both physical and chemical processes. The first affects the stability of materials, the second acts through chemical corrosion, such as oxidation, hydration reaction, as well as dissolution of carbonates and solubilization of some elements (Gutarowska 2007).

Rooms, which are most often affected by mould contamination, include bathrooms, kitchens, basements, balconies, verandas, as well as exterior walls and floors covered by various types of materials (Gutarowska 2007). Materials tested in this study are very often used in these places.

Kumar and Verma (2010) in their contribution and also many others authors present moulds Aspergillus spp. and Penicillium spp. as the commonest moulds in buildings. That is the reason why these strains of moulds were used. Thus, tests simulate real conditions very well.

This contribution deals with various materials commonly used in the wooden buildings (interior and exterior) from the point of their natural resistance to moulds and bacteria. Each material has different composition, different surface etc. These characteristics determine how microorganisms, especially moulds, will survive on their surface.

## MATERIAL AND METHODS

### Materials

*Tested building materials*

The following materials were tested. There is also a brief description of using these materials in the wood constructions and in the case of varnishes there is also a procedure of the preparation of samples. Size of all tested samples except varnishes was 40 x 40 mm.

- **plasterboard** with special treatment against dampness, used in bathroom where higher dampness is expected
- **special construction plasterboard** without any treatment on the sample surface, used in conditions, where the strong mechanical stress is expected

- **particleboard** consists of wooden chips stick together with glue (phenolformaldehyde adhesive)
- **extruded polystyrene** used for external insulation of buildings
- **oriented straight board (OSB)** consists of perpendicularly oriented wooden chips stick together with glue (phenolformaldehyde adhesive)
- **mineral wool (yellow) and mineral wool (green)** used as filling between wooden column of frame of wood constructions
- **plywood** used as design element on wall facing in the interior or as furniture, consists of spruce tree veneers stick together with glue (ureaformaldehyde adhesive)
- **cement bonded particleboard** is a cement bonded particleboard with smooth natural grey cement surface. It is suitable for walls, facades, floors, roofs and fire-resistant applications.

*Wood materials*

- **pine tree (massive)** impregnated against moulds grow
- **larch (massive)** nonimpregnated, it could be used finished by varnishes or without finishing
- **spruce (massive)** nonimpregnated, it is usually used without finishing with varnishes
- **oak veneer** nonimpregnated
- **beech veneer** nonimpregnated

*Varnishes*

- **acrylic water-borne varnish and two components (solvent-borne) polyurethane varnish** used for finishing wood products (e.g. furniture). Samples were prepared as a one layer of coating on filter paper. The application was performed according to producer's instructions. Samples were dried for 5 days before testing under conditions: relative moisture content of 45 ± 5% and temperature of 23 ± 2°C. Circular samples of diameter 50 mm were cut.

*Tested germs*

The following tested moulds were used: *Aspergillus niger* (CCM 8155), *Chaetomium globosum* (CCM 8156), *Penicillium funiculosum* (CCM F-161), *Gliocladium virens* (CCM 8042) and *Paecilomyces variotii* (CCM F 566). The following tested bacterial strains were used: *Staphylococcus aureus* (CCM 4516) and *Escherichia coli* (CCM 4517). Microorganisms were obtained from the Czech Collection of Microorganisms, the Czech Republic.

*Media for cultivation and dilution of microorganisms*

For tests with moulds Malt agar (MA) (obtained from HiMedia Laboratories Pvt. Ltd., Mumbai, India) for cultivation and solution of mineral salts (prepared according to EN 14119) for dilution were used. For tests with bacteria Plate count agar (PCA) (obtained from HiMedia Laboratories Pvt. Ltd., Mumbai, India) for cultivation and tryptone water for dilution and preparing the bacterial suspension were used. Each medium was sterilized in autoclave (121°C for 15 min). Agar plates were prepared according to standard microbiological techniques.

*Test standards*

Qualitative standard Testing of textiles - Evaluation of the action of microfungi (EN 14119, 2004) was used for the determination of the resistance to mould growth. Testing was performed according to methods A2 and B1.

Quantitative standard Antimicrobial products – Test for antimicrobial activity and efficacy (JIS Z 2801, 2012) was used for the determination of the resistance to bacterial growth.

## Methods

*Evaluation of resistance to moulds - EN 14119, method A2*

Test specimens were placed into sterile Petri dishes. The tested mould spore suspension in solution of mineral salts was adjusted to a concentration of $10^6$ spores/mL by Bürker counting chamber. Prepared suspension was homogenously spread onto specimens. Petri dishes were placed into wet chamber (minimal relative moisture content 95%) and incubated at 29±2°C for 28 days. After this time, the growth of moulds on the sample was evaluated. Three parallels were tested for each sample, average value is expressed in results. Samples were evaluated by naked eye and by microscope with the magnification 40x.

*Evaluation of resistance to moulds - EN 14119, method B1*

Malt agar (MA) was poured into sterile Petri dishes to provide agar layer 5 mm in depth. After solidification of agar tested specimens were placed on the surface of the agar. Mould spore suspension used for method A2 was homogenously spread onto specimens and agar. Petri dishes were incubated at 29 ± 2°C for 28 days. After this time, the growth of moulds on the sample and around the sample was evaluated in the same way as for method A2. Three parallels were again tested for each sample and average values are expressed in table of results.

*Evaluation of resistance to bacteria - JIS Z 2801*

The tested bacteria were adjusted to a concentration of $1.10^5 – 3.10^5$ CFU/mL by a McFarland nephelometer in tryptone water. 0.4 mL of the inoculum were added on all tested sample surfaces (50 x 50 mm) placed in sterile Petri dishes and covered with sterile PE foil (40 x 40 mm). Each sample was tested three times (in the final results only average values are mentioned). The number of bacteria was determined in time 0 h (immediately after the inoculation) and after 24 h of incubation of bacteria on the sample surface at 35°C according to the following procedure. Tested samples were shaken out with 20 mL of tryptone water and the number of bacteria was determined by the standard microbiological technique - plate count method. This is a method in which the number of bacteria is calculated by counting the number of colonies according to a ten-fold serial dilution. 1 mL of each dilution was pipetted into a Petri dish and approximately 15 mL of PCA agar were poured to the dishes and mixed. After the incubation of the Petri dishes for 24 h, the number of bacteria in 1 mL was counted (cB in CFU/mL). The final number of bacteria M was calculated according to the following equation:

$$M = c_B \cdot 20,$$

where: M - the number of bacteria per specimen (CFU),
$c_B$ - the bacterial concentration obtained by the plate count method (CFU/mL),
20 - the volume of the shake-out medium (mL).

# RESULTS AND DISCUSSION

## Evaluation of the resistance to mould growth according to the test method: EN 14119, method A2

The following Tab.1 shows results of the resistance of samples that were placed into Petri dishes without agar medium to moulds. Results say how moulds naturally grow on the sample surface only under wet conditions without agar medium.

*Tab. 1: Results of the resistance to mould growth (EN 14119 method A2).*

| Sample | Mould growth on the sample surface | |
|---|---|---|
| | (%) | Evaluation |
| plasterboard | **0** | no grow visible under microscope |
| special construction plasterboard | **25** | slight grow visible by naked eye |
| particleboard | **100** | moderate grow visible by naked eye |
| extruded polystyrene | **< 5** | very slight grow visible by naked eye |
| OSB | **0** | no grow visible under microscope |
| mineral wool (yellow) | **0** | no grow visible under microscope |
| mineral wool (green) | **0** | no grow visible under microscope |
| plywood | **100** | slight grow visible by naked eye |
| cement bonded particleboard | **0** | no grow visible under microscope |
| pine tree (massive) | **0** | no grow visible under microscope |
| larch (massive) | **< 5** | very slight grow visible by naked eye |
| spruce (massive) ⊥ | **0** | no grow visible under microscope |
| spruce (massive) II | **0** | no grow visible under microscope |
| oak veneer | **0** | no grow visible under microscope |
| beech veneer | **0** | no grow visible under microscope |
| water-borne varnish | **0** | no grow visible under microscope |
| solvent-borne varnish | **0** | no grow visible under microscope |

Nearly all tested samples (specifically, plasterboard, impregnated pine tree, spruce, oak veneer, oriented straight board, both mineral wools, cement bonded particleboards and both varnishes) showed excellent results. There are many reasons for these good results, e.g. special treatment against moisture (in the case of plasterboard), impregnation against mould growth (pine tree massive), content of resin (spruce massive) and tannin (oak veneer) or used glue which is able to kill microbes. Extruded polystyrene and larch had also very good results. Plywood and particleboard showed no resistance to fungal growth which means a critical point for mould contamination in wood-based buildings.

## Evaluation of the resistance to mould growth according to the test method: EN 14119, method B1

Tab. 2 expresses results of the antifungal activity of samples that were placed into Petri dishes with agar medium. This medium gives a nourishment to moulds and facilitate their growth. Results say how moulds grow on the sample surface in the presence of nutrient. This test puts more demanding conditions for samples to show their effect, because moulds can use the nutriments from agar.

*Tab. 2: Results of the resistance to mould growth (EN 14119 method B1).*

| Sample | Mould growth on the sample surface | |
|---|---|---|
| | (%) | Evaluation |
| plasterboard | **100** | heavy grow visible by naked eye |
| special construction plasterboard | **100** | heavy grow visible by naked eye |
| particleboard | **100** | heavy grow visible by naked eye |
| extruded polystyrene | **< 5** | slight grow visible under microscope |
| OSB | **100** | moderate grow visible by naked eye |
| mineral wool (yellow) | **15** | slight grow visible by naked eye |
| mineral wool (green) | **30** | slight grow visible by naked eye |
| plywood | **100** | heavy grow visible by naked eye |
| cement bonded particleboard | **0** | no grow visible under microscope |
| pine tree (massive) | **50** | moderate grow visible by naked eye |
| larch (massive) | **100** | heavy grow visible by naked eye |
| spruce (massive) ⊥ | **100** | heavy grow visible by naked eye |
| spruce (massive) II | **100** | moderate grow visible by naked eye |
| oak veneer | **100** | heavy grow visible by naked eye |
| beech veneer | **100** | heavy grow visible by naked eye |
| water-borne varnish | **50** | slight grow visible by naked eye |
| solvent-borne varnish | **100** | heavy grow visible by naked eye |

Results showed that only cement bonded particleboard and water-borne varnish are absolutely resistant to mould growth. Extruded polystyrene is also very resistant. Pine tree and both mineral wools were able to reduce moulds on their surface. The inhibition of moulds on pine tree massive is due to impregnation. The rests of tested samples were completely covered by moulds after 28 days of cultivation. This result means that samples contain no antifungal treatment. Mould spores occur everywhere and there is a need to add that in the case of conditions where a higher supply of nourishment (e.g. organic dust particles), air moisture and no draught is present, moulds will contaminate these surfaces.

In the Figs. 1 - 6 we can see clearly the differences between two methods A2 and B1. Moulds in Petri dishes without agar medium grow less intensively.

*Fig. 1: Result of mould growth on particleboard tested according to EN 14119, method A2.*

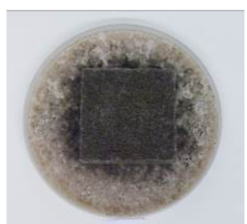

*Fig. 2: Result of mould growth on particleboard tested according to EN 14119, method B1.*

*Fig. 3: Result of mould growth on oriented straight board (OSB) tested according to EN 14119, method A2.*

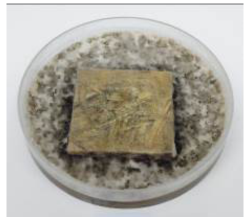

*Fig. 4: Result of mould growth on oriented straight board (OSB) tested according to EN 14119, method B1.*

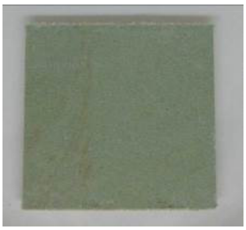

*Fig. 5: Results of fungal growth of plasterboard (SDK) tested according to EN 14119, method A2.*

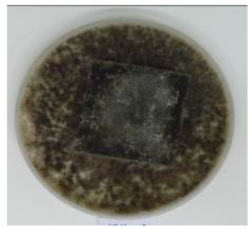

*Fig. 6: Results of fungal growth of oriented straight board (SDK) tested according to EN 14119, method B1.*

Some results of resistance to moulds were very unexpected. Oak wood is generally known to have very strong antimicrobial effect (Sohretoglu 2007, Andrensek 2004). Nevertheless, this study does not confirm it at all. Oak veneers were completely covered by moulds after 28 days, test according to EN 14119, method B1. When one starts to look for possible reasons of this difference, he finds out there are differences in used strains, concentration of fungal spores, cultivation medium, time of cultivation. All of this can have an impact on the results.

On the contrary, some results of this contribution confirm others research. For example, (Sterflinger et al. 2013) in his study tells that from the microbiological and hygienically point of view, plaster and board made of bloated perlite are presented as being the most appropriate materials for thermal indoor insulation. This contribution confirms it, extruded polystyrene showed one of the best results.

One of the main aim of this study was to compare the antimicrobial activity of wood itself (raw wood) and wood treated with varnishes. Five types of wood and two types of varnishes were tested. The contradictory results of oak wood were mentioned above. The best results from tested wood materials showed pine tree (evaluated according to the method B1). Solvent-borne two components varnish had no resistance to mould grow, while water-borne varnish had considerable resistance against moulds (Fig. 7 and Fig. 8).

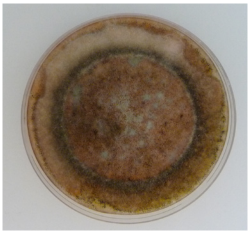

*Fig. 7: Result of mould growth on solvent-borne varnish tested according to EN 14119, method B1.*

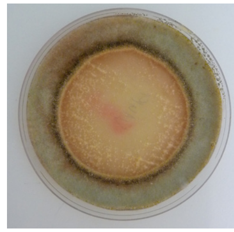

*Fig. 8: Result of mould growth on water-borne varnish tested according to EN 14119, method B1.*

Moreover, resistance to bacterial growth was also tested in the case of wood and varnishes. The reason is the fact that not only spores of moulds in the indoor air but also bacteria can cause serious health problems. Wood and varnishes were chosen because they are materials that can be in contact with human hands so there is a great risk to spread infections.

## Evaluation of the resistance to bacterial growth according to the test method: JIS Z 2801

Following Tab. 3 shows that tested bacteria are able to survive and multiply only on the solvent-borne varnish. All kind of tested woods (except larch in the case of *E. coli*) completely killed tested bacterial strains. The same effect expressed the water-borne varnish.

The reason for the strong antimicrobial effect of water-borne varnishes is the presence of preservative biocides that are included in all water-borne varnishes. A water base is susceptible to microbial contamination and that is the reason why preservative biocides must be added. Their antimicrobial effect remains active even after a formation of a dry film. There is no need to contain preservative biocides in solvent-borne varnishes because of their solvent base. Thus, dry film does not have any antimicrobial effect.

*Tab. 3: Results of the antibacterial activity of water-borne and solvent-borne coating materials and various wood materials tested according to JIS Z 2801.*

| Sample | Used germs | CFU/sample 0 h | CFU/sample after 24 h |
|---|---|---|---|
| water-borne varnish | *S. aureus* | $6.8 \cdot 10^4$ | < 20 |
| | *E. coli* | $7.3 \cdot 10^4$ | < 20 |
| solvent-borne varnish | *S. aureus* | $6.6 \cdot 10^4$ | $8.3 \cdot 10^5$ |
| | *E. coli* | $7.2 \cdot 10^4$ | $9.8 \cdot 10^6$ |
| pine tree (massive) | *S. aureus* | $6.3 \cdot 10^4$ | < 20 |
| | *E. coli* | $6.9 \cdot 10^4$ | < 20 |
| larch (massive) | *S. aureus* | $6.3 \cdot 10^4$ | < 20 |
| | *E. coli* | $7.3 \cdot 10^4$ | $2.3 \cdot 10^2$ |
| spruce (massive) ⊥ | *S. aureus* | $6.5 \cdot 10^4$ | < 20 |
| | *E. coli* | $7.3 \cdot 10^4$ | < 20 |
| spruce (massive) II | *S. aureus* | $6.6 \cdot 10^4$ | < 20 |
| | *E. coli* | $7.1 \cdot 10^4$ | < 20 |
| oak veneer | *S. aureus* | $6.7 \cdot 10^4$ | < 20 |
| | *E. coli* | $7.0 \cdot 10^4$ | < 20 |

< 20 means the limit of method JIS Z 2801

Heavy antibacterial effect of wood can be explained by the fact that samples were after 24 h of cultivation absolutely dry (all liquid was absorbed into the wood). It means bacteria penetrated to the sample together with the liquid and were caught in the sample. No living cells were present on the sample surface after 24 h (results < 20 in Tab. 3).

## CONCLUSIONS

1. Results showed that plywood and particleboard are not at all resistant to mould growth. Moulds grow very well on these surfaces under conditions of higher air moisture and without draught. These materials pose a risk of contamination by moulds which can of course spread to other materials used in wood-based constructions and to the air and thus can be very dangerous to human.
2. Cement bonded particleboards is resistant to mould growth according to both tested methods (the best result of all building materials). Surface of cement bonded particleboard probably contains chemicals that reduce a mould growth. Extruded polystyrene and mineral wools show also very good effect against moulds.
3. Water-borne varnishes are considerable resistant to microbial growth because of preservative biocides inside them that are still active even after formation of dry film, while solvent-borne varnishes have no resistance to microorganisms.

This article was focused on the air quality of wood-based buildings. Expressed results could help to avoid the mould contamination of materials used for this type of constructions.

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