Analysis of failures of waterproofing cladding layers of terracotta tiles

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Abstract. The article is focused on one of the most important roof cladding layers – the waterproofing cladding layer of terracotta tiles. Its detailed analysis covers the main waterproofing cladding layers in terms of their material characteristics and installation methods. The article concludes by formulating principles for the correct design of the main waterproofing layer/construction.

1 Introduction

Roof cladding has been part of the main waterproofing construction in various shapes since the beginning of our era. Around the 1970s – 1980s, the attic space (usually of existing residential houses) started to be used for living or other purposes involving permanent people's presence.

One of the objectives of research was to formulate the principles for the effective design of waterproofing layers in roof cladding systems and prove the effect of the main waterproofing layer on the life span of the whole roof construction [1].

2 Experimental verification of reliability and durability of waterproofing cladding layers

The analysis of the mechanical and physical characteristics of waterproofing cladding layers was made on two reference houses with residential attics. The first house had a wrongly installed roof cladding without an effectively ventilated air layer and the roof tiles were locally damaged, the cladding age is 18 years, the slope of roof planes 25°and 32°.

The second reference house had a faultlessly installed roof covering with fired clay roof tiles in accordance with regulations in force ten years ago with a slope of 40°.

Experimental testing covered waterproofing cladding layers installed pursuant to ČSN standards in force and manufacturer's assembly principles, including the correct workmanship of the ventilated air layer. The waterproofing cladding was subjected to impermeability and tensile bending strength tests. This experiment is focused on the properties of materials embedded in the roof envelope in direct connection to their life expectancy and mechanical and physical characteristics.

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Roof tiles were sampled from the waterproofing cladding layer of both houses and successively subjected to standard tests. To compare the characteristics, roof tiles of the original batch stored in the interiors of both houses were also tested. These roof tiles were tested for impermeability under ČSN EN 539-1 [2], testing method No. 2 and for tensile bending strength under ČSN EN 491:2012 [3].

2.1 Mechanical and physical characteristics of waterproofing layer materials on experimental houses

The results of the tests of mechanical and physical characteristics for differently installed roof tiles from two experimental houses "Trojanova" (without a ventilated air layer) and "U Smaltovny" (faultless roof cladding) are presented in Tables 1 and 2:

Table 1. Evaluation of the impermeability test of plain roof tiles.

IMPERMEABILITY TEST - Trojanova				**IMPERMEABILITY TEST – U Smaltovny**			
Date of testing: 28. 12. 2015 from 5.00 a.m.				Date of testing: 13. 1. 2016 from 8.30 a.m.			
Specimen No.	Weight [g]	Time to first drop [hours]	Impermeability coefficient	Specimen No.	Weight [g]	Time to first drop [hours]	Impermeability coefficient
Roof tiles sampled from a cellar deposit				**Roof tiles sampled from a cellar deposit**			
N1	1674.2	2.25	0.888	N1	1577.1	no drop	0
N2	1678.5	5.5	0.725	N2	1571.8	no drop	0
N3	1675.5	5	0.75	N3	1567.5	no drop	0
N4	1674.9	5	0.75	N4	1570.1	no drop	0
Mean values		**4.44**	**0.78**	**Mean values**			**0**
Roof tiles embedded in the roof envelope				**Roof tiles embedded in the roof envelope**			
S1	1764.9	no drop	0	S1	1631.7	no drop	0
S2	1686.8	no drop	0	S2	1654.6	no drop	0
S3	1764.5	no drop	0	S3	1626.3	no drop	0
S4	1772.5	no drop	0	S4	1624.2	no drop	0
Mean values			**0**	**Mean values**			**0**

In the roof tiles sampled from the house with a cladding without a ventilated air layer, no leakage occurred in any of 4 embedded (used) roof tiles during the testing time, i.e. 24 hours. So-called "tightening", i.e. closing of pores occurs in the used roof cladding and, successively, the roof cladding does not leak during its life span. In the roof tiles from the deposit, which had not been exposed (embedded), the average impermeability coefficient measured from 4 specimens reached a value of 0.778.

Laboratory tests of the roof tiles from the second reference house manifested that the roof tiles which had been embedded in a correctly installed main waterproofing cladding layer as well as the roof tiles stored in the deposit had not lost their principal property – impermeability during the 10-year period.

Table 2. Tensile bending strength of roof tiles.

RH Trojanova, Prague 2				**RH U Smaltovny, Prague 7**			
TENSILE BENDING STRENGTHS OF ROOF TILES - Experiment 1 and 2							
Specimen No.	Weight [g]	Hanging length [mm]	Max. force F [N]	Specimen No.	Weight [g]	Hanging length [mm]	Max. force F [N]
Roof tiles embedded in the roof envelope				**Roof tiles embedded in the roof envelope**			
1	1673.6	352	792	1	1631.7	336	1173
2	1680.8	351	913	2	1645.6	337	1168
3	1675.5	352	886	3	1626.3	336	1168
X	-	-	-	4	1624.2	336	993
Mean value	**1676.63**	**351.67**	**863.67**	**Mean value**	**16334.2**	**336.3**	**1126**
Roof tiles sampled from a cellar deposit				**Roof tiles sampled from a cellar deposit**			
X	-	-	-	5	1577.1	349	1100
4	1765.4	349	1100	6	1571.8	351	1158
5	1687.7	351	1158	7	1567.5	348	1229
6	1763.2	348	1229	8	1570.1	355	1346
Mean value	**1738.77**	**349.33**	**1162.33**	**Mean value**	**1571.6**	**335.8**	**1304**

Laboratory testing verified a decrease in the tensile bending strength of 3 specimens embedded for 18 years over an unventilated air layer by nearly 25% compared to 3 specimens of identical roof covering stored in the deposit of spare roof tiles on the first overground storey of the same house for the same period of time. On the contrary, 4 specimens embedded over a ventilated roof layer showed a decrease in the tensile bending strength of 14% after 10 years against the specimens from the deposit. In both reference houses, however, the minimum standard strength of plain terracotta roof tiles required for the whole life span of 600N was observed with a reserve.

3 Analysis of failures and defects of roof cladding envelopes

The experiments included the assessment of the causes of failures and defects of roof cladding envelopes. Based on long-term statistics of repairs and reconstructions of 2011 – 2015, the results presented in this study are as follows (internal statistical data of rbe Koláčný s.r.o. Company) are presented in Tables 3 and Fig. 1:

Table 3. Causes of roof reconstructions over a period of 5 years.

STATISTICS OF RECONSTRUCTIONS OF ROOFS with terracotta and concrete roof tiles												
year / number of roofs												
Cause of repair	**2015**		**2014**		**2013**		**2012**		**2011**		**Total**	
Roofs in total	42	%	56	%	38	%	33	%	46	%	215	%
Additionally built-in attic space	15	35.7%	21	37.5%	8	21.1%	3	9.1%	12	26.1%	59	27%
Wrongly installed under-roof / poor workmanship	13	31.0%	10	17.9%	9	23.7%	2	6.1%	4	8.7%	38	18%
Excessive age of roof covering	14	33.3%	25	44.6%	21	55.3%	28	84.8%	30	65.2%	118	55%

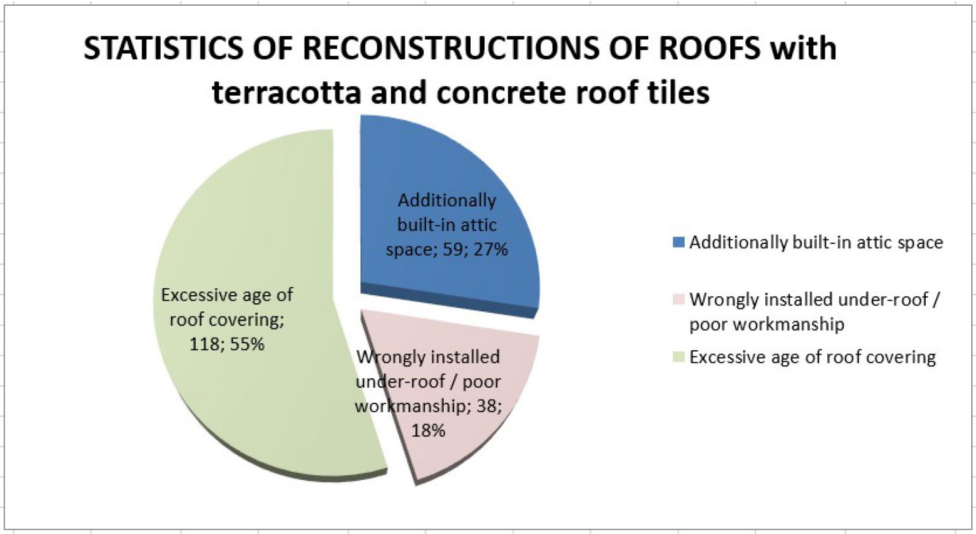

Fig. 1. Causes of roof reconstruction over a period of 5 years – comparison.

Note: The age considered excessive is a period exceeding 60 years.

The above statistics clearly show the growing trend in repairs and reconstructions due to wrongly installed roof cladding or using unsuitable materials. These are, in particular, poor-quality foils for additional waterproofing layers, which are the most frequent cause of a necessary reconstruction.

4 Principles of effective design of main waterproofing constructions in roof cladding systems

These are the principles for the installation of waterproofing constructions of roof envelopes and their effect on the roof construction's life span. The determination of the design life expectancy of the main waterproofing construction requires respecting Instruction F (directive of building products 89/106/EEC) and Eurocode ČSN EN 1990. The above documents recommend a design life expectancy of constructions for common buildings replaceable with some effort of 25 years, it is the life expectancy of easily replaceable constructions. The recommended life expectancy of repairable constructions is

10 years. Therefore, according to this directive, the additional waterproofing layer should have a required life expectancy of 25 let, whereas the life expectancy of 10 years would suffice for the roof tiles. If the manufacturers of additional waterproofing layers declared a life expectancy lower than 10 years, i.e. significantly shorter than the guarantee provided by the manufacturers of roof covering systems, the guarantee for the roof covering could not be fully used.

The above facts clearly show that the life expectancy of additional waterproofing layers in the roof construction in terms of the life span of roof envelopes with a waterproofing cladding layer over residential attics is of principal importance both in terms of the roof surface area and detail.

An ideal solution in the environmental and economic perspective is to unify the durability of the main and additional waterproofing layers within the principal waterproofing construction to the maximum extent possible. This is the optimum in terms of the roof cladding cost-effectiveness.

5 Conclusion

The following conclusions can be drawn from the above facts for an effective design and installation of roof cladding systems:

- unify the design life span of the products of the main waterproofing construction both over the surface area and in detail,
- change the approach to the design of additional waterproofing layers (quality of material solution, change in loading, elimination of negative mechanical, UV and chemical effects),
- search for materials with long-term reliable characteristics for additional waterproofing layers.

A faultless and long-term functional principal waterproofing construction undoubtedly necessarily requires a suitable structural design of the whole roof cladding and the right choice of individual materials for each layer. The materials must be mutually compatible and their planned life expectancy should be identical or at least similar. Correct workmanship during the installation is the last condition so that the principal waterproofing construction is fully functional from the very beginning. Only if the above conditions are fulfilled, a long-lasting and perfect roof can be achieved.

References

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3. *ČSN 491:2012, Concrete Roof Tiles and Trim Tiles for Roof Covering and Wall Cladding – Testing Methods* (2012)