Paper presented at the 5th Global Insulation Conference, London, 4th and 5th of October 2010

The Effect of Moisture on the Compressive Strength and Walkability of Roofing Insulation

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Introduction

Since many years several researchers have studied the effect of moisture on certain properties of insulation materials. This paper deals with the moisture effects on the properties of roofing insulation, specifically compressive strength and walkability. When roofing work is being carried out, this necessarily means that the roofers must walk on the roof. This dynamic form of loading can seriously damage the insulation material and, as a result, the waterproofing layer. After completion, (highly) intensive foot traffic on a roof can also cause damage. Research has shown that a relatively high moisture content of the insulation in some cases can have a significant negative effect on the walkability. The problems mainly affect roofs with mineral wool (rock fibre) insulation, but frequent dynamic loading can also damage other insulation materials.

Mechanically fastened roof-waterproofing systems are particularly susceptible to such damage. Over time, the decrease in thickness and compression strength of the insulation can lead to penetration of the waterproof layer by the screw heads.

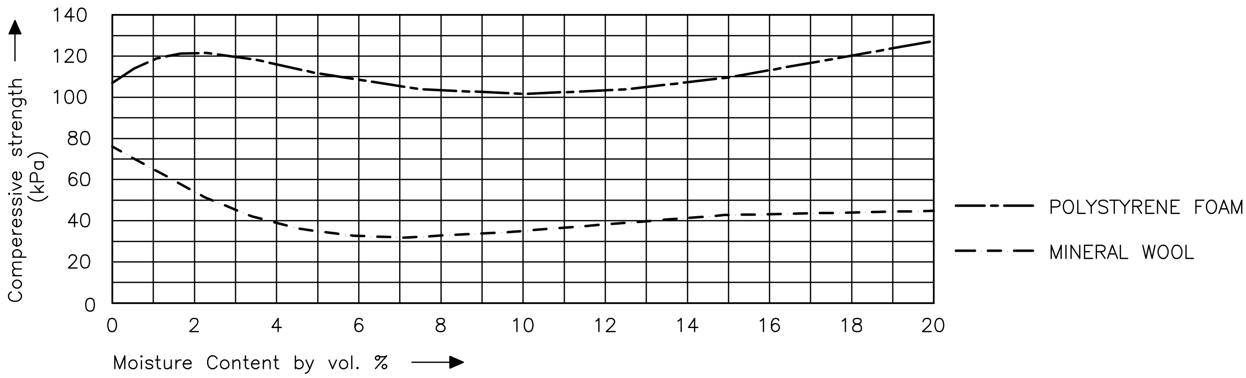
Figure 1. Damage to roofing material caused by collapse of the insulation due to frequent foot traffic: the screw heads of the mechanical fastening have perforated the PVC membrane.

Figure 2. The MWR insulation has become soft, due to (excessive) pedestrian traffic. Various leaks (caused by penetration by screw heads) have been repaired, but new perforations are already starting to appear.

Effect of moisture on compressive strength

In the open research literature very little information can be found on an important effect of moisture on an insulation property, the compressive strength. Figure 3 shows this effect for MWR and EPS, as measured by BDA [1, 2006].

Figure 3. The effect of moisture on the compressive strength (at 10% deformation) of some insulation materials [1, 2006].



The meaning of this phenomenon becomes specifically clear when also the effect of moisture on the walkability of the roofing insulation boards insulation is determined. This is in actual practice also a very important property. The determination of walkability is a relative new research area, one of the first papers on this topic was presented by Hendriks [2, 2002]. The principles will be explained in the next paragraphs.

New test method to determine walkability

Examples from practice have shown that certain insulation products are still susceptible to damage from repeated foot traffic loading, despite possessing good (dry) compression strength. The European standard EN 12430:1998 "Thermal insulating products for building applications - Determination of behaviour under point load" [3, 1998] has proved completely inadequate as a means of evaluating the walkability of insulation. Yet the standard was developed by the CEN commission concerned to enable determination of a product's resistance to forces resulting from foot traffic. However, it is a static test that establishes not much more than the compressive strength of the insulation product, and provides no useful information about behaviour under dynamic loading.

In 2002 BING, the European organisation of PUR foam manufacturers, commissioned BDA Keuringsinstituut to continue the development of an existing BDA test method that simulates the dynamic loading from foot traffic. This method, which is now known as the BDA Marathon Man Test, was significantly improved on the basis of extensive follow-up research. The test enables the walkability of insulation products to be classified.

Aim of the research

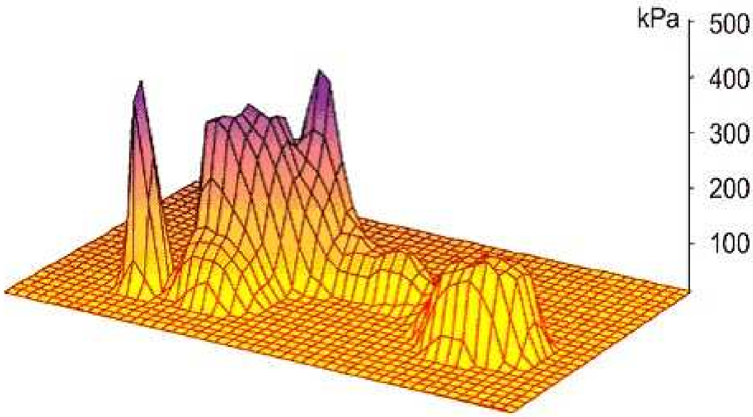
The aim of the research programme was to arrive at a reproducible test method to classify the walkability of insulation products. The method must give a reliable prediction of whether, and to what degree, an insulation product is suitable to withstand repeated loading from foot traffic, both during the installation of the roof and its operational use. Moreover, the associated classification system must enable insulation products to be classified according to their suitability for a particular roof usage.

Determination of 'foot traffic loading'

Although laboratory tests are generally intended to predict the behaviour of (building) products in practice, they can never exactly simulate the actual conditions. In laboratory tests, for example, reproducibility is an extremely important factor, while in reality, practical situations are always different. To arrive at reasonably safe pronouncements, it is often necessary to slightly exaggerate the practical situation. On the other hand, a test must not be so severe that it no longer bears any relationship to real situations. This proved to be the case in the first phase of the development of the BDA Marathon Man Test. Tests with the original load combination leaded to completely unrealistic results, especially with regard to mineral wool. The material was pulverised after only a few load cycles, which obviously bears no relationship to examples from practice.

The load to be applied therefore had to be determined with greater precision. Luckily, a great deal of research had already been carried out in this field by specialists in footwear biomechanics, such as Prof. Hennig [4, 2002]. Figure 4 shows the detailed pressure distribution under the bare foot in the shoe of a walking person. The highest pressure of 416 kPa was measured under the big toe. If we take 50 mm x 20 mm as the approximate measurements of a big toe, this corresponds to a load of no higher than about 400 N. The pressure under the heel was 312 kPa. Taking into account a relatively small surface area (≈ 1500 mm^2) for the loaded section as the heel descends, the load transferred becomes 470 N. This is around 60% of the weight of the average pedestrian.

Figure 4. Dynamic footprints during walking, as measured by Hennig [4, 2002]



In the example of a roofer carrying a roll of sheeting on his shoulder, this translates to a load of 600 N (approx. 60 kg). To be sure of reasonably safe predictions, it was finally decided to take a load of 750 N (approx. 75 kg), after further comparative tests.

The test device

The machine that exerts the dynamic 'foot traffic load' on the insulation product has a battery of 16 cylinders with the artificial heels as described (diameter: 80 mm). Every load cycle consists of four sub-cycles. During a sub-cycle, the specimen is subjected to loading at the specified 750 N from each of the stamps in succession, combined with a radial (torsional) force of 250 N. This force simulates the friction between the shoe sole and the substrate during walking. To make the load on the product as evenly distributed as possible, the specimen is moved after every sub-cycle, in a direction perpendicular to the previous orientation, by half of the centre-to-centre distance between the cylinders. Figure 5 shows the test device.

Initially, the load was exerted directly on the insulation product for the simple reason that this is the easiest way of ensuring reproducibility. However, the results obtained were too divergent from practical experience. Furthermore, it turned out that the specimen had to be fixed in the sideways direction, to avoid unrealistic damage to the edges of the insulation. This corresponds well with the practical situation, since each insulation board in a roof *is* fixed at the sides. In the present form of the test, the specimen (of 600 x 600 mm) is therefore covered with a 1.2 mm layer of non-reinforced EPDM film, clamped into a wooden frame that fits around the specimen exactly. Once again, EPDM was chosen because of the need for maximum reproducibility. Other results show an important influence of the roofing system.

Figure 5. The test device. It was christened the BDA Marathon Man shortly after the first prototype was built in 2001

Classification system

Table 1 shows the version of the classification system that is currently applied by BDA. The number of cycles per class is determined by a (safe) estimation of the number of times the roof will be walked on in the usage category concerned. The visual results of the tests were also evaluated by BDA consultants and inspectors who are highly experienced in the assessment of roofs with 'foot traffic damage'. Such measures were applied to achieve the best possible correlation with actual practice. The criterion against which the specimens are tested (reduction in compression strength < 15 %) is also based on practical experience.

Table 1. Classification of walkability of insulation products

Class	Number of cycles	Meets criterion[1)]	Walkability	Suitability roof for pedestrian traffic
0	5	no	Not	Not suitable
1	5	yes	Limited	Incidental pedestrian traffic during inspection and maintenance of roofing
2	10	yes	Good	frequent pedestrian traffic during inspection and maintenance of building services equipment
3	30	yes	Intensive	Daily pedestrian traffic (galleries, roof terraces)

[1)] Criterion: compressive strength no more than 15% lower than initial value

Results

Several insulation products were tested in the various test programmes [7, 8 en 9]. The most important results are summarised in table 2.

Table 2. Most important general results from the walkability testing conducted on several combinations of insulation products and roofing systems and the associated classification

Insulation material	Roofing system	Classi-fication [1)]	Walkability	Suitability roof for pedestrian traffic
Mineral wool standard	EPDM	0	Not	Not suitable
Mineral wool standard	PVC	1	Limited	Incidental pedestrian traffic during inspection and maintenance of roofing
Mineral wool double density	EPDM	1	Limited	Incidental pedestrian traffic during inspection and maintenance of roofing
Mineral wool double density	2 layers modified bitumen	2 - 3	Good to intensive	Frequent to daily pedestrian traffic
Expanded polystyrene with light facing and low density	EPDM	1	Limited	Incidental pedestrian traffic during inspection and maintenance of roofing
Expanded polystyrene with light facing and low density	PVC or 2 layers modified bitumen	2 - 3	Good to intensive	Frequent to daily pedestrian traffic
Expanded polystyrene with standard facing and density	EPDM	2	Good	Frequent pedestrian traffic during inspection and maintenance of building services equipment
Faced polyurethane and expanded polystyrene with heavy facing and high density	EPDM	3	Intensive	Daily pedestrian traffic (galleries, roof terraces)

[1)] Indicative values

All tests are carried out in triplicate. The initial compression strength is determined using a separate specimen from the same batch. The measured variations in compression strength are therefore partly due to the normal distribution of compression strength found in the insulation product.

On the basis of the results it is recommended to declare the walkability classification of an insulation material always in combination with the roofing system. A general declaration of the walkability classification may only be related to a combination with a 1.2 mm layer of non-reinforced EPDM film.

Figure 6. Mineral wool specimen (MWR Duo1) after 10 load cycles: little external damage, but the compression strength has decreased by over 80%. This type of result is also found in practice (in cases of damage).

Need for European Standard

The results obtained are in good agreement with practical experience. This makes the test method an important aid in predicting the suitability of an insulation material for a particular application. It was therefore recommended that the current European standard, whose predicting value is negligible, be replaced by (a modified form of) the BDA method. However, such a test method is not specifically useful to obtain a Manufacturer's Declared Value. Therefore it is recommended to develop a relatively simple dynamic test method that could be based on the existing standard EN 13793 [10, 2003]. This European Standard specifies equipment and procedures for determining behaviour of test specimens cyclic loading conditions. It is applicable to thermal insulating products. The selection of the conditions of the test shall be derived from the specific requirements of the intended application. The BDA method could be used to validate a modified version of this existing standard. In this respect the available numerous results with the BDA method will be very useful.

Effect of moisture on walkability

So far the effect of moisture on the walkability of insulation boards has not been tested on a range of products. This will be done in a later phase of an extensive research programme, sponsored by Plastics Europe. Table 3 gives the results of pilot tests done on double density MWR.

Table 3. Effect of moisture on the walkability of double density MWR in the framework of a pilot study [11, 2006]

Test specimen	Compressive strength (kPa)		
	Initial	After moisture load(48 h 70˚C, 95% RH)	After moisture load and 30 cycles of walking load (see table 1)
1	54,9	33,8	2,0
2	51,9	33,9	-*)
3	52,8	32,7	-*)
Mean value	53	33	2,0

***)** Not measurable because of destruction of the test specimen

The moisture load is applied by placing the sample, covered by a roofing sheet over a tank containing water of 70 ˚C in a laboratory room with a standard climate of 23 ˚C and 50% relative humidity. The moisture pick-up is caused by condensation under the roofing sheet. This pilot test shows the dramatic effect of the combination of moisture and foot traffic on the compressive strength of MWR insulation. The full research programme will provide more information of other combinations of moisture content and walking loads for different roof insulation materials. It is clear however that this aspect needs special attention.

Conclusions

1. The new BDA test method of determining an insulation product's resistance to foot traffic gives realistic results and enables insulation products to be classified in relation to the usage of the roof.
2. The walkability classification of an insulation material always must be declared in combination with the roofing system. A general declaration of the walkability classification may be related to a combination with a 1.2 mm layer of EPDM .
3. The development of an extension to the existing European standard EN 13793, to be used as the basis for a Manufacturer's Declared Value on Walkability deserves recommendation; the BDA method could be used for validation of this new version of the standard.
4. The effect of moisture on both the compressive strength and walkability properties of different roof insulation materials can be significant and needs further investigation.

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