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Analysis of Structure and Deformation Mechanisms of Mineral Wool Slabs under Compression

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The products of mineral wool are widely used for thermal insulation of buildings, both at construction of new buildings and at renovation of old ones. The mechanical resistance and stability of them, as well as their energy saving and heat saving requirements are in most cases related to the essential specifications of the building. The mechanical characteristics of these products are subject to structure of material, density, content of binder in the product and to technology of production. Subject to the latter, mineral wool products with different fibrous structure are received, therefore, for the structure of each type, the individual structural models are developed attempting to describe the properties of fibrous systems. The deformability of mineral wool products is conditioned by mobility of fibrous structure, which shows up best under compression by short term loads. This study established the impact of various thicknesses and deformations on changes in structure of rock wool products. It also established that the thickness of mineral wool products conditions and influences considerable changes in their structure.

Keywords: stone wool slabs, structure, deformation, mineral fiber.

INTRODUCTION

The thermal insulation products from mineral wool have been recently and widely used in the buildings envelopes and constructions [1]. Mineral wool is allocated to fibrous composites, since is composed of binding (binder) and reinforcing (filaments) phases [2]. The structure of fibrous insulating material of this type is peculiar, and its properties in various directions are mostly not even. The information provided in literature allows stating that the structure of mineral wool products is determined by technological factors and the physical and mechanical properties are the subject of orientation of filaments in the product. The properties such as tensile strength, shear strength and compressive strength depend on direction of filaments and their orientation in the product [3].

Structurally mineral wool may be described as a spatial system composed of a lot of filaments located in a certain order in respect of each other and intertwined, mostly in the binder-fiber places of filament contacts [4].

The adjusting of the fibrous structure (possibility to change the direction of the fiber arrangement) at the stage of the technological process of production determines the thermal, strength, deformation and exploitation properties in the rigid mineral wool products [5].

However, due to the peculiarities of the process of production, there are always a certain percentage of filaments randomly oriented.

When mineral wool is produced by the traditional technology, the majority of filaments on the conveyor net are oriented in the horizontal direction [5].

The properties of mineral wool and other fibrous materials are dependent on filament orientation, since the direction of fibers exerts an influence on value of physical and mechanical indices [6].The control of fibrous structure by regulating the direction of filament orientation in the bed of fiber at stage of technological process of production allows to make products of mineral wool with desired heat insulating, strength and deformation properties [7, 8].

The orientation of fibers direction in the product structure changes the characteristics of various materials [9, 10], since the properties of materials with spatial fibrous structure is not even in various directions. If the direction of orientation of dominating filaments in the structure is known, then relating it to mechanical and deformation characteristics, one can regulate the orientation of filaments. This enables to optimize the processes of production or to make products with desired strength [10].

In the production of mineral wool products, the conveyor technological lines are used mostly [11]. Depending on the type of the technological line and fiber regulation possibilities, the thermal insulating mineral wool products may be received with different structure: directional (horizontal), chaotic (when the fibres are orientated randomly and in different directions unevenly) or vertical [12, 13]. For the structure of each type, the individual structural models are developed to describe the properties of fibrous systems and their dependence on structural peculiarities and characteristics [14, 15].

It is known that the orientation of fibres direction in the product structure changes its strength properties. The products of the chaotic fibre orientation (where the direction of most fibres coincides with the major face) have the higher deformation ability and relative elasticity. Whereas, the products of the directional fibre orientation have the much higher compressive strength, as their

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structure consists of the fibres and their groups are oriented perpendicularly against the major face. The deformation of such products is considerably lower. With the increase in the compressive load, the product deformation increases, and when it reaches the critical limit (1.5 % – 5 % deformation), it yields [5, 15].

The orientation of filaments in the bed of fiber can be changed by various technological equipment installed directly in the conveyor line of production (mostly past the chamber of fiber precipitation).

As it is almost impossible to measure the orientation of single filaments in the structure within rather a big area, it is usually accepted to measure the average inclination angle of filament groups dominating in the macrostructure in respect of the axis under investigation. In opinion of some authors [3, 16, 17], the fibrous structure may be depicted as a complex system of links composed of a lot of elementary systems put one on another (graphically, on the axis of two coordinates to be depicted as a triangle where the angles α and β vary between 0° and 180° (Fig. 1). Each such system is composed of the following structural elements: filament, small particles of organic material and non-filament insertions of melt.

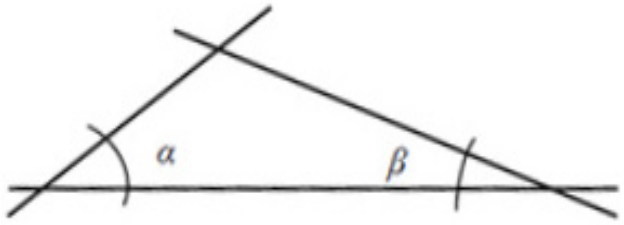


Fig. 1. An element of the stone wool structure comprising three fibres [3, 16, 17]

The aim of this work is to evaluate the relationship between the stone wool slabs thickness and fibrous structure as well as establish mechanism of deformation and effects of compressive load on the structure.

2. MATERIALS AND TECHNIQUES

For the tests, the slabs of stone wool with synthetic (phenol – formaldehyde resins) binder, of partially corrugated and horizontally layered structure, produced acording to [18] and meant for thermal insulation of superposed flat roofs, monolithic cellar overlappings and floors on ovelappings. The nominal thickness of used slabs was the following: 50, 100, 160 mm, and the density 95 kg/m3. The stone wool slabs were tested after 1 – 1.5 month since their production. They were conditioned at temperature of (23 ±5) °C. For the tests of macro- and microstructure, the samples sized (100×100×20) mm were used. Their surfaces were investigated by optical microscope MOTIC with a digital camera and software for investigation of structure of materials, as well as by scanning electron microscope "EVO 50 EP" (Carl Zeiss SMT Ltd., Germany, low vacuum mode, vacuum in the chamber of samples ~60 Pa). The prepared stone wool samples were thrust between two metal plates and tightened from both sides by screws (Fig. 2).

So prepared samples were put into the optical and scanning electron microscopes for performance of the macro- and microanalysis. For macroanalysis the (×25 – ×50) enlargement was used, for microanalysis the (×1000 – ×5000) enlargement. The macroanalysis covered the general observation of structure of product and binder distribution in the product, while the microanalysis deals with analysis of single fiber of product and the binder between them.

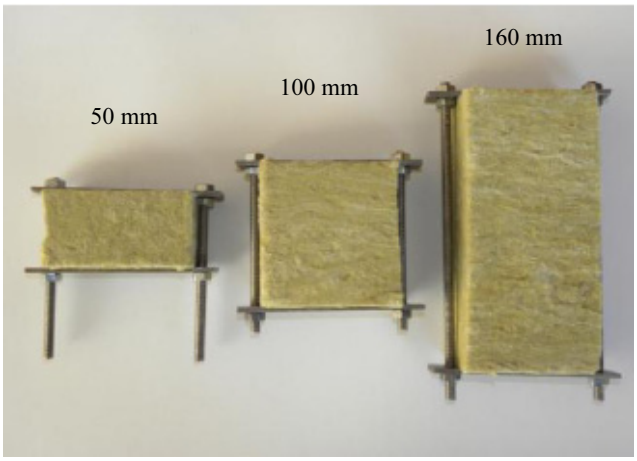


Fig. 2. The total sample image

3. TESTS RESULTS AND DISCUSSION

First of all, the macroanalysis of stone wool samples was performed. The visually observable light and dark zones of stone wool were divided into separate layers by special markers. For comparison, the adjacent light and dark layers of similar thickness were selected (Fig. 3). By screws, the samples of stone wool were compressed perpendicularly to direction of the markers. Upon compression of sample until 25 % deformation, the highest deformations were observable in the light layer (Layer 1), while in the dark layer (Layer 2), no deformations were observed or they were insignificant. The dark layers showed a higher content of binder in the product, while the light ones lower. Due to lower content of binder, the light layers are weaker and for that reason they more deform.

The deformation mechanism in stone wool products of various thickness as is different. First of all, this is conditioned by technological factors. In the samples 50 mm thick the thicknesses of light and dark layers are lower and the binder itself is more evenly distributed in the whole product. Upon compression of the products with such thickness both at deformation of 25 % and 60 %, no greater shift of individual layers is observed. Furthermore, comparing the products of different thickness at the same deformation, their decrease in thickness differs greatly. If they to be compared at the mentioned deformation of 25 %, then for the product 50 mm thick, it is only 12.5 mm, while for products 160 mm thick, it reaches even 40 mm, i. e. they differ by 3.2 times.

Upon unscrewing the screws, by which the sample was held at compression, the deformations of sample disappear, i.e. the sample recovers its former shape. One cannot observe any changes in the macrostructure of sample after load removal. Nevertheless, as shown by the

previous tests of cyclic compression [19], the stress of compression of sample and in particular the module of elasticity at compression considerably decrease after the first cycle of compression. For this reason, the tests of microstructure were performed for the stone wool.

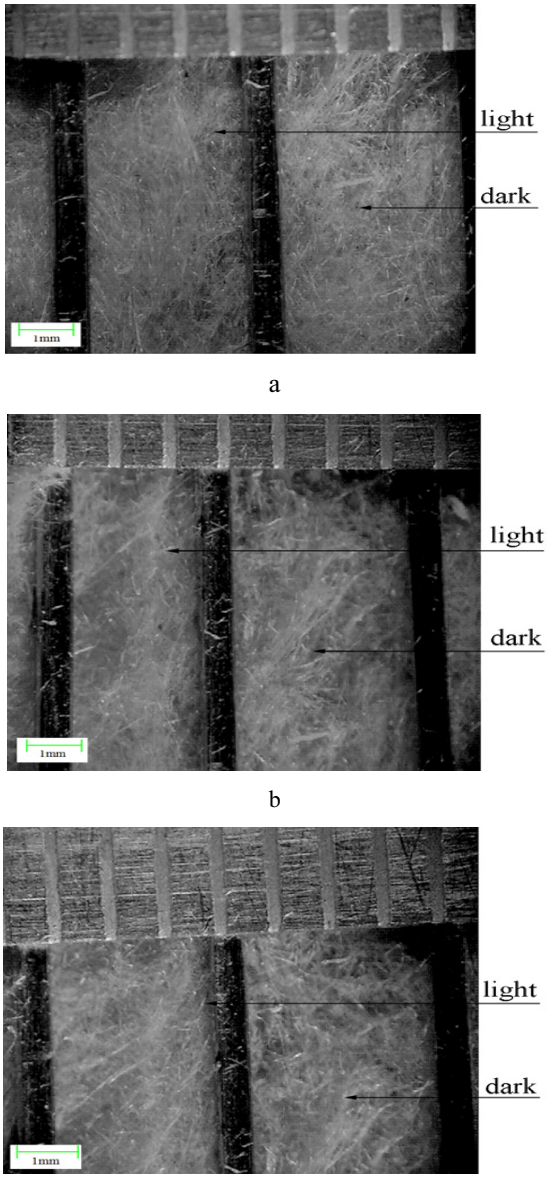


Fig. 3. Stone wool samples are divided into light and dark layers. Specimen thickness $d = 160$ mm (×50): a – the sample deformation 0 %, b – 25 % deformation of the sample, c – samples after removing the load

In the tests of microstructure, first of all, virgin samples are inspected (Fig. 4, a, b). In the structure one can observe direct stone wool fibres overlapping one another.

Then the samples were compressed until specified deformation by means of screws. According to the previous investigations [20], it was established that the limit of elasticity expires approximately at deformation of 3 % [21]. The tests of stone wool microstructure, performed at such deformation, did not show any changes in structure (Fig. 5, a, b). At deformation of 10 % (at which most often the relative value is determined for certification of products), the changes in structure are not observed within this length, though the determination goes almost in the middle of this length where lies the limit of flow of material [22 – 24]. Since all effective thermal-insulating materials contain a great amount of air, then by compressing, the fibres have much free space to shift and the structure remains almost unchanged.

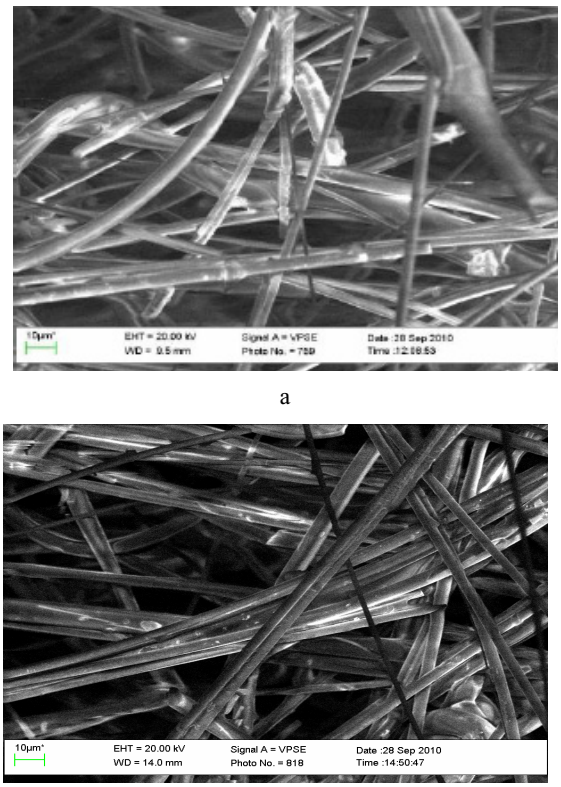


Fig. 4. Stone wool samples with 0 % deformation: a – 50 mm (×2000); b – 160 mm (×2000)

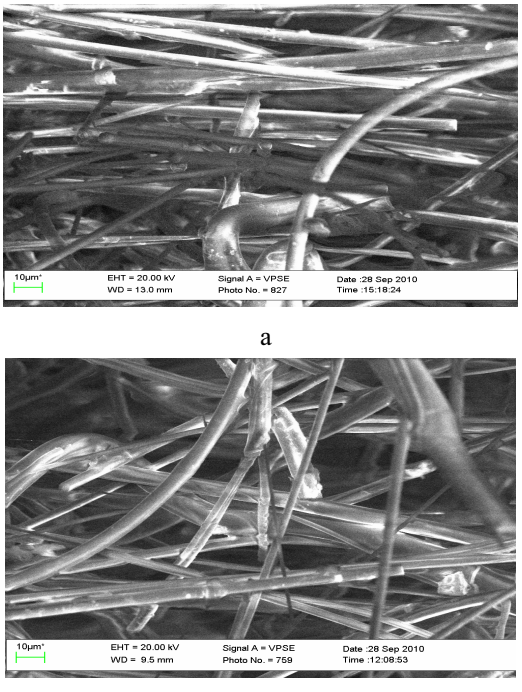
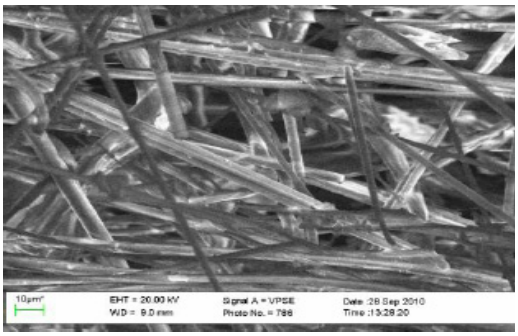


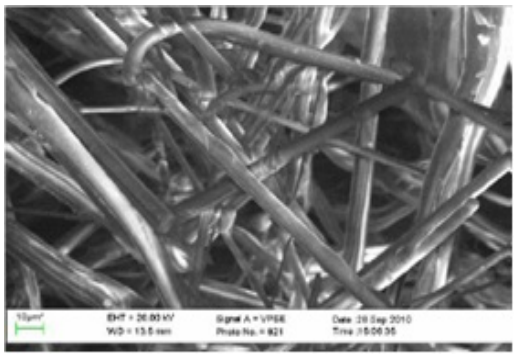
Fig. 5. Stone wool samples with 3 % deformation: a – 50 mm (×2000), b – 160 mm (×2000)

In the samples 50 mm thick the compacting starts at ~60 %, in the samples 160 mm thick this occurs almost twice earlier, at deformation of ~30 %.

Thus in the structure of samples the following changes are observed: the fibres of samples start bending and the whole structure of sample looks chaotic, as fibres are bent in different directions and no parallel fibres are remaining (Fig. 6, a, b).

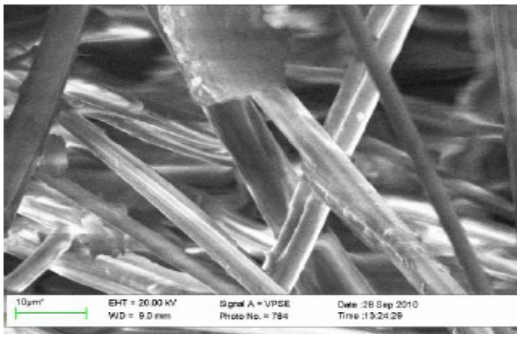


a

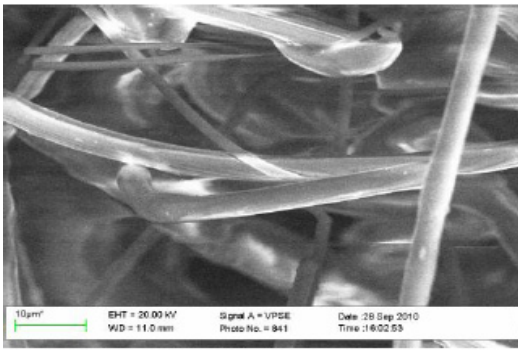


b

Fig. 6. Deformed stone wool samples: a – 50 mm – 60 % deformation (×2000); b – 160 mm – 30 % deformation (×2000)



a



b

Fig. 7. The samples after removing the load: a – 50 mm (×5000); b – 160 mm (×5000)

However, no destruction of the sample is observed in the structure, i. e. the intercrossing fibers remain bound by binder with no destroyed links between these filaments to be seen. As mentioned above, stone wool products after one cycle of compressing become weaker. The investigations of microstructure were performed to this aim after removal of load. Even the products deformed to 60 % (50 mm thick) almost fully recovered their initial shape.

In Fig. 7, a, one can see that though the shape of sample was recovered, nevertheless, many fibers remained bent. To the second compression of stone wool samples are resisting already fewer fibers, therefore, the strength of samples decreases, as well as the elasticity module at compression.

DISCUSSION

The analysis of results shows that deformation mechanism of mineral wool under compression is very complicated. Deformation mechanism of such material depends on the slabs thickness, fibrous orientation, deformation level et al.

In [24 – 26] deformation mechanism of mineral wool studied by digital image correlation and microtomography methods was studied. In these articles changes of structure were described as changes of specimen density and strain heterogeneity zone and strain localization bonds. In our opinion analysis of structure must be analysed in two levels – macro-changes the total sample and separate zones and micro-changes of individual fibres and contacts between them. Such analysis takes more knowledge about changes of mineral wool structure under compression and strain localization bonds.

Analysis of material structure of macrostructural level helps to explain the general mechanism of deformations in these products. After compression and removal of load, the stone wool products acquire their initial shape. Furthermore, comparing the products of different thickness at same deformation, their decrease in thickness differs greatly. If they are compared at the mentioned deformation of 25 %, then for the product with 50 mm thickness of, it is only 12.5 mm, while for products with 160 mm thickness of, it reaches even 40 mm, i. e. they differ by 3.2 times.

CONCLUSIONS

1. Deformation mechanism of stone wool products under compression depends on the material thickness. In thin products distribution of binder is even over a product thickness and compressive stress of such product is higher than of thick products.

In thick products light and dark zones due to uneven distribution of binder are observed. In light zones small quantities of binder are injected and such zones are more vulnerable.

2. The materials microstructure investigations show the weakening of stone wool products after the first cycle of compression: the weaker and less flexible filaments still remain deformed though the product acquires its initial shape, and they exert but little impact on strength of product in the process of repeated compression.

In the samples of 50 mm thickness the compacting starts at ~60 %, in the samples of 160 mm thickness this

occurs almost twice earlier, at deformation of ~30 %. Thus in the structure of samples the following changes are observed: the fibers of samples start bending and the whole structure of sample looks chaotic, as fibers are bent in different directions and no parallel fibers are remaining.

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