Basalt is of the family of igneous rocks which means it melts when heated up, as a thermoplastic material. Basalt is volcanic magma which has solidified in the open air. Basalt has always been used for its hardness in road surfacing and in construction as a filling stone. Also after brought to the molten stage, it is molded into construction parts, as for example floor tiles and as internal lining in steel pipes transporting abrasive and hot compounds. Basalt stones come with different chemical compositions, and only particular chemical compositions and physical characteristics of basalt allow its extrusion into continuous thin filaments with useful properties. The nominal diameters of these continuous filaments now come in the range 9 to 24 μm. It is mainly used (as crushed rock) in construction, industrial and high way engineering. One can also melt basalt (1300-1700°C) and spin it into fine fibres. When used as (continuous) fibres, basalt can reinforce a new range of (plastic and concrete matrix) composites. It can also be used in combination with other reinforcements (e.g. basalt/carbon).
Brief history

Credit has to be given to a Frenchman from Paris, Paul Dhé, who in 1923 got a US patent for extruding filaments from basalt. It is known that in the 1950/60’s in Moscow and in Prague, in today’s Russia and Czech Republic – among other places, research in this field started. In the 60’s and 70’s, intensive R&D efforts took place in the North-West of the USA – which by the way has large basalt deposits. In the 1960/70’s the defense ministry of the Soviet Union got interested in the potential of this technology for military and space applications. All R&D was concentrated in Kiev, Ukraine. Budgets were unlimited. This research eventually became successful. The technology was kept secret and the object of little publication. The research institutes and production plants dealing with it were off limits. It is in 1990/92 in Perestroika, the technology was declassified. This allowed its application in the civilian field.

General Basalt Fiber’s Technical Features as Belowt

- Permanent flame retardant resistance: Limiting oxygen index (Loi) > 70
- Extraordinary high softening temperature (point): > 1200 Celsius degree
- Operating temperature range: from -260 to 760 Celsius degree
- High tensile strength (breaking strength): 3200 MPa
- Low elongation at break: 3.1 %
- High elastic modulus: 89 GPa
- Density: 2.7 gram/cubic centimeter
- Low thermal conductivity: 0.035 W/m•K
- High sound absorption coefficient: 0.95
- Low moisture absorption: 0.1 %
- High specific volume resistance: 1x1012 ohm•m
- Radiation proof lead equivalent: 0.0073 mm Pb

Water-absorbing capacity of basalt fiber is much less than 1%, of fiberglass - up to 10-20%. For comparison, industrially manufactured fiberglass, especially of neutral composition, absorbs substantial amount of moisture in humid air, which weakens its physical-technical and longevity properties and eventually leads to fiber damage. On contrary, low nonvolatile water absorbency of basalt fiber ensures stability of thermal and physical characteristics in case of continuous service. Basalt fiber has high chemical stability and pertains to the first dimming class and greatly exceed fiberglass in acid, alkali and steam resistance characteristics. The disadvantages of fiberglass compared to basalt fiber are spinosity of threads, and discharge of the finest dust at disintegration of thermal insulation at thermal-cycle loads. Due to high elastic modulus, basalt fiber strength is 35-40% higher than that of fiberglass - the fiber is more elastic, non-spinous. Materials of basalt fiber have a greater operating life as compared to materials of fiberglass. Super-thin basalt fiber is firmly knitted by natural cohesive attraction. Basalt fibers are chemically stable to exposures of aggressive means and steam and do not accumulate radiation. Costs of basalt fiber production are markedly lower (by 15-20%) compared with other mentioned fibers manufacture owing to one-stage basalt fiber production scheme. Yield of basalt fiber from basalt is 100%. Notice also that basalt fiber producing facilities are compact, environmentally safe and waste-free (only products of combustion of natural gas, cooled and cleaned in filters, are emitted to atmosphere). The sole factor, hindering wide application of basalt fiber in Russia is very low volume of their commercial production.

The present story reports the study on cement mortar with basalt fibre intrusion for its mechanical and physical properties by Institute of Structural Engineering at Poznan’ University of Technology.

Outcome Experimental Investigation Carried out in Institute of Structural Engineering at Poznan’ University of Technology:

Tests have been carried out in the laboratory of the Institute of Structural Engineering at Poznan’ University of Technology. The aim of the tests was to check the influence of added basaltic fibre on some selected physical and mechanical properties of cement mortar. An attempt was made to calculate the optimum amount of the basaltic fibre, allowing the best mechanical properties of the mortar to be achieved. For mortar preparation cement CEM I 32.5R and standard quartz sand were used (according to PN-EN 196-1). The tests were carried out to check bending
strength and ultimate compressive strength after 3, 7 and 28 days. The measurement of shrinkage in the first 28 days of mortar curing was also made. The tests were performed on standard cement mortar prisms with dimensions of 4 x 4 x 16 cm. The results of preliminary tests show that the effective impact of the basaltic fibre on the change of basic physical and mechanical properties of the mortar decreases in case of the fibre amount higher than 2% and lower than 0.2% of the mortar weight. That is why samples for the tests were made by adding to the mortar the basaltic fibre totalling 0.3, 0.8, 1.3 and 1.8% of the mortar weight. The basaltic fibre used for tests was cut into pieces of approx. 6.5 mm. Base prisms with no fibre content (0.0%) were also made up. During the whole period the samples were stored under laboratory conditions in the temperature of 18°C and a relative air humidity > 90%.

Test results for the bending strength

The results achieved during the tests are presented in (Table 1). The presented results are the arithmetic average of measurements made on six samples. Standard deviation of the obtained results of bending strength is between 1.6 to 8.3%. The analysis of the data included in (Table 1) demonstrates that the addition of basaltic fibre increases the bending strength by 13% on average. The achieved increase is practically independent from the amount of added basaltic fibre. After 7 days of mortar curing the bending strength is highest. The highest increase of the bending strength (of approx. 6.5%) in comparison with the base mortar is achieved by adding basaltic fibre equalling 0.8% of the mortar weight. After 28 days of curing the achieved bending strength was lower than after 7 days. The reason for this was probably the use of cement of high initial strength for tests. For prisms with an additive of fibre equalling 0.3%, 1.3%, 1.8%, the bending strength decreased by another 7.5% in comparison with the base prisms (0.0%). The lowest decrease (approx. 4.5 %) was noticed in samples with the fibre content totalling 0.8% of the volume. It may be assumed that the main reason for this is high fragility of the used basaltic fibre, its relatively small elongation at break and high adherence to the mortar. The mortar which was used to make samples is characterized by fairly high shrinkage. After more than twelve days of curing, the shrinkage strength causes cracking of the basaltic fibres. This would explain a high increase of bending strength after 3 days of curing and a lower increase after 7 days as well as a significant decrease after 28 days of mortar curing. Observation of the prisms’ cross-sections after the tests revealed that the basaltic fibre was diffused in the mortar at random and spatially. During breaking of the samples, approx. 90% of the fibre got broken and the remaining 10% were torn out of the mortar. This demonstrated considerable adherence of the mortar to the basaltic fibre.

<table>
<thead>
<tr>
<th>Bending Strength</th>
<th>Basaltic Fibre Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.00</td>
</tr>
<tr>
<td>After 3 Days</td>
<td>5.3</td>
</tr>
<tr>
<td>After 7 Days</td>
<td>7.8</td>
</tr>
<tr>
<td>After 28 Days</td>
<td>6.7</td>
</tr>
</tbody>
</table>

Table 1: Bending Strength of Mortar Prism

Ultimate compressive strength

The achieved test results are presented in (Table 2). The presented results are the arithmetic average of measurements made on 12 samples. Standard deviation for achieved results of ultimate compressive strength is between 3.0 and 8.1%. After 3 days of curing a significant increase of ultimate compressive strength (of 10%) was observed only for the amount of 0.8% of the fibre in the mortar. For the remaining tested prisms, with the fibre content of 0.3%, 1.3% and 1.8%, the ultimate compressive strength remains on the same level in comparison to the base samples or is slightly higher, which is within the measurement error. After 7 days of curing we can observe stabilization of the strength for 0.3%, 0.8% and 1.8% of the fibre content. In case of the fibre amount equalling 1.3%, we can see a slight decrease of the ultimate compressive strength. However, the reason of such results might be a measurement error. After 28 days of curing, test results are much more differentiated. For small contents of fibre we can observe a significant increase (over 20% for 0.3% of the fibre content and almost 8% for 0.8% of the fibre content). For the fibre amount equalling 1.3%, the strength compared to that of the base samples did not change and for the content reaching 1.8% there was a visible decrease of the strength (of over 15%). The mortar with 1.8% of the fibre content was characterized by much worse workability.
and worse possibility of its thickening than others. This might have had a decisive impact on its lower ultimate compressive strength.

<table>
<thead>
<tr>
<th>Ultimate Compressive Strength</th>
<th>Basaltic Fibre Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>After 3 Days</td>
<td>30 31 33 30 31</td>
</tr>
<tr>
<td>After 7 Days</td>
<td>40 41 40 37 41</td>
</tr>
<tr>
<td>After 28 Days</td>
<td>39 47 42 39 33</td>
</tr>
</tbody>
</table>

Table 2: Ultimate Compressive Strength

Test results concerning shrinkage

The shrinkage values given in (Table 3) are the arithmetic average of measurements made on 3 samples. The measurements were made with the accuracy of ± 0.005 mm. From the achieved results we may see that the highest shrinkage value is achieved in the specimens with no fibre content. Shrinkage after 28 days decreases proportionately to the increasing fibre content in the mortar. Measurements made after 3, 7 and 14 days of curing show that the proportionality of the shrinkage to the fibre content is maintained during the whole 28-day period of measurements. It proves that the phenomenon of breaking of the basaltic fibre, observed during the tests of bending strength after the first week of mortar curing, practically has no impact on weakening of its anti-shrinkage properties. The fibre, broken into small pieces, considerably decreases the shrinkage of the mortar. The data from (Table 3), shows the dependence between the fibre content in the cement mortar and its 28-day shrinkage. It was conclude by the researchers that in the tested range of the basaltic fibre content as mentioned above will cause the decrease of shrinkage of the cement mortar by approx. 15 to 20%.

<table>
<thead>
<tr>
<th>Basaltic Fibre Content (%)</th>
<th>Shrinkage (mm/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>0.077</td>
</tr>
<tr>
<td>0.30</td>
<td>0.058</td>
</tr>
<tr>
<td>0.80</td>
<td>0.060</td>
</tr>
<tr>
<td>1.30</td>
<td>0.046</td>
</tr>
<tr>
<td>1.80</td>
<td>0.027</td>
</tr>
</tbody>
</table>

Table 3: Average Shrinkage of Mortars after 28 days of curing

Research Outcome

From the analysis of the test results as well as the observation made during these tests the Researchers concluded that: The addition of basaltic fibre causes noticeable increase of 3 and 7 day bending strength; after 28 days of curing, there is a decrease in bending strength and The highest bending strength in comparison to the base samples was achieved in case of 0.3 to 0.8% of the fibre content after 7 days of curing and the highest ultimate compressive strength was achieved in case of 0.3 to 0.8% of the fibre content in the cement mortar after 28 days of curing and exceeding the amount of the fibre addition by 1% results in significant worsening of mortar workability and possibility of its thickening and adding the basaltic fibre to the mortar causes a smaller shrinkage, proportionate to the fibre content. Researchers recommended an optimum amount of the basaltic fibre in the mortar, allowing the best mechanical properties to be achieved, ranges from 0.5% to 0.8% of the cement weight. The addition of basaltic fibre in the content as mentioned above will cause the decrease of shrinkage of the cement mortar by approx. 15 to 20%.

Basalt fiber is a modern XXI-century material, combining ecological safety, natural longevity, and fire safety (incombustibility). Good understanding of its useful mechanism continues to be gained. These fibers, alone or combined with others, go through the first transformation step, producing: e.g. wovens and nonwovens, braids, knits and chopped fibers. Coatings can be applied for outdoor use, for oils and greases resistance, for impermeability to water and permeability to air, for anti-slip and anti-soiling, for continuous skin contact, for high abrasion resistance, for heat insulation through intumescence, for colored or fluorescent appearances, etc. Basalt has advantage over glass fibres interms of mechanical, thermal and chemical properties. In a time where we are looking towards fibre’s in concrete, Basalt fibres can be a very good choice considering its beneficial characteristics. However more detailed research may be needed to explore its other effects on the cement concrete/mortar.

Reference

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