Isolation systems based on energy efficient basalt fiber wares

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Abstract. The article analyzes the properties of wares based on continuous and staple basalt fiber which offers high fire-resistance, thermal insulation capacity, vibrancy resistance, noiseproofing, as well as chemical durability including durability to arctic atmosphere and marine climate effects. That sort of fiber is a core for construction fabric, canvas and special-purpose products.

The research findings of usage of modifying mineral additions as part of basalt working mass are reported. Modifiers’ introduction allows to decrease temperature interval of working mass’ melting by 80-100 °C. Herewith optimal melt’s amorphy degree is reached within the temperature range of working mass melting of 1400-1520 °C. It causes energy intensity’s reduction while manufacturing fabrics and the ability of using more technological smelting units and ways to rework the melt into a fiber.

Fabrication of special buildings’ engineering structures isolation systems using basalt fiber fabrics, canvas and fire-resistant rolled materials which guarantees standard value of thermal resistance is proposed.

1. Introduction

Continuous and staple basalt fiber are used as a reinforcing component in polymer composite materials, which are highly resistant to all types of climate effects and subterranean water effects; in manufacturing of plates and mates based on different types of synthetic blenders (fig. 1); in manufacturing of basalt plastic tubes and steel bars [1-3]. Alkali-resistant basalt fiber is widely used in manufacturing of heavy or hollow concrete with fiber reinforcement [4-6].

Figure 1. A plate based on basalt fiber.
Continuous basalt fiber are used as a master component of non-burning woven materials, which are highly service and chemical durable. Depending from the way of manufacturing and an accessory part, the products are used as a firestop, vibration protection, thermal insulating material. These properties of the materials allow their usage in designing of isolation systems of devices working in the polar region circumstances, and for designing oil and gas platforms’ building structures’ isolation systems in particular [7-9].

A huge amount of developed and upside fields is concentrated on the territories to the north of 67-th parallel, that is why the building technologies’ development (including development of special building systems) in the extremely low nature temperatures and permafrost circumstances is one of the prioritized directions for the national building industry. In no small measure, this relates to oil platforms which are planned to place on a shelf of the Kara, Barents, Pechora and other seas in the Arctic Ocean [10-12].

Regulatory requirements to the materials and structural systems used in the construction of shelf platforms (oil and gas lifting) should be under the requirements which are set in the international or national legislation related to shipbuilding and oil and gas platforms’ building. In addition to these rules, classification societies as Det Norske Veritas (DNV) or Lloyd’s Register of Shipping (LRS) can place their additional demands [13-15].

The dangerous factor is a fact, that ignition can cause hydrocarbons’ inflammation which changes the circumstances of a burning process seriously. The temperature can reach 750 °C (and higher) in a fire area, and the firepower itself can be followed by chemically active sub-stance evolution [3, 4]. In case of Russian platforms the situation is deteriorated by the climate circumstances of the polar region, which are harder than in North and Norwegian seas (where the areas are affected by the Gulf Stream), but under their parameters the enclosing structures for the constructions on oil platforms are designed nowadays [16-18].

2 Experimental & Results

Raw materials for the basalt fiber are the basic magmatic rocks. Naturally basalts melts turn into a crystalline state after the volcanic eruption and slow lava cooldown, so we can say that major energy cost for basalts’ primary melting and processing are done by nature. Basalt rocks’ choose and study works for basalt fiber’s production are underway in Russia, Iran, Kazakhstan, Tajikistan, Uzbekistan, Armenia.

For staple basalt fiber production the working mass composition is selected depending from an original rock composition, individually on the basis of an amount of required acidity modulus (Ma = 3.6-5.2). The higher an acidity index is, the higher an acid resistance and fiber’s strength properties are, but the higher charges for getting liquid melt and reworking it into a fiber.

Technological process includes following steps: heating and melting of the basalt rock, degasification and homogenization of the liquid melt, reworking the melt into a fiber. Into basalt fiber technologies the major and energy intensive technological limit is melting of the prepared rock (working mass) and reworking the melt into a staple, as well as continuous fiber (fig. 2).
A goal of researches taking place in MSUCE (NRU) is determination of major regularities and optimal parameters of the basalt rock based working mass melting processes for production mineral (basalt) fiber, working off the technologies of melting of basalt and melts homogenization. Practical aspect of the researches is formation recommendations about producing mineral fiber with lower energetic consumption - gas and electrical energy and preservation of working properties of the fiber and products based on it.

By a process of basalts melting following process tasks are being solved:
- basalt’s heating and melting (destruction crystalline structure);
- overheating of the basalt melt in order to receive required level of uniformity, melting of more hyperthermal basalt rock inclusions (quartzites, mica, magnesites and others which has higher melting temperature), eutectics state assurance;
- receiving of homogenized and degasificated melt with required viscosity.

Research and experience of basalt fiber production show that melting of basalt working mass in the furnace should be conducted within the temperature interval which is 150–320 °C higher than the basalt rock’s upper crystallization limit is. Basalt rock’s upper crystallization limit temperature from different deposits depends on basalt’s chemical makeup and lies within the temperature range of 1215–1280 °C, while the melt’s temperature is kept of about 1500–1600 °C.

The properties of mineral (including basalt) fiber are characterized by two macro indicators: the acidity modulus and the viscous modulus. The acidity modulus (Ma) allows to esteem fiber’s properties and the viscous modulus (Mv) characterizes melt’s properties including it’s melting temperature. As following from the goal to be thought, a choice of mineral add for a working mass having no impact to the Ma (acidity modulus) but reductive the Mv (viscous modulus) as well as working mass melting temperature became a research objective.

Mineral melt’s viscous is mainly determined by two factors:
- the melt’s chemical makeup and the temperature in a smelting unit. Research shows that mineral modifier adding (at the quantity up to 3,5%) allows to decrease melt’s viscous by 25-30% within the 1400–1500 °C interval.

One of the major factors of production high quality fiber is receiving of amorphous homogenized melt, which means complete fracture of crystalline structure and melting of forcing inclusions in basalts. It is achieved by assuring of required basalts melt parameters in a melting zone and in a homogenization zone of melting furnace and by feeding of a melt with required amorphous and viscous degree to a melt to fiber conversion unit. In a table 1 the datas about strength of mineral fiber received from a basalts melt with a different basalt melting temperatures and with special mineral adds are listed.
Table 1. Basalt fiber properties

| Melt’s temperature, °C | Maximum tensile strength, MPa |
|------------------------|-------------------------------|
|                        | Basalt working mass | Modified working mass |
| 1100                   | —                   | 1200                |
| 1200                   | —                   | 1550                |
| 1300                   | 1600                | 1820                |
| 1400                   | 1870                | 2230                |
| 1500                   | 2300                | 2570                |
| 1600                   | 2550                | 2600                |

The results analysis shows that due to melt temperature increase amorphous degree rises. Essential amorphous degree and fiber strength criteria rise while basalt working mass melting is noted when a melt is overheated in the temperature interval 1500–1600 °C. Temperature interval of basalt working mass melting 1500 – 1600 °C ensures a fuller transfer of basalt from crystalline to amorphous state with melt’s amorphous degree up to 96%.

3. Discussion

External wall constructions systems of oil and gas platforms should comply with requirements and safety standards. Outer linings should retain their properties in the circumstances of oceanic climate and atmosphere along with low temperatures; should safe structure elements from negative atmospheric forces. Enclosing elements’ (walls) framework should have low heat conductance, herewith components to isolate aggregates, which generate vibrations and to minimize vibration and sound transmission to construction structure elements should be planned. Heat-insulation layers should ensure external walls statutory heat transfer resistance, be unimflammable and include no components which constitute an ecological danger. Internal lining as well should ensure required protection from a flame impingement, be made of waterproof materials and fully meet the demands of interior finishing.

In insulation systems the following manufactures based on basalt fiber are recommended to use: fabrics (cloth), plates (mates, canvas), special fireproof rolled materials.

Fabrics (cloth) tissued of continuous basalt string are unimflammable and are characterized with resistance in an excited environment (tabl. 2). Fabrics form an exterior outline of isolation system and their vibration isolation characteristics allow to use fiber in the form of gasket between the frame elements and external skin. Resistance to aggressive alkaline and acid medium makes them a perspective material for oceanic climate conditions. Coil length 100, 200 m allows to isolate sizable surfaces during a single cycle.

Table 2.

| Name of indicator                              | Fiber’s mark                  |
|------------------------------------------------|------------------------------|
| Width, cm.                                      | BF - 11 | BF - 13 | BRF - 100 |
| Thickness, cm.                                  | 100 + 2% | 100 + 2% | 100 + 1%         |
| Mass per area g/m²                               | 0,27 + 0,03< | 0,22 + 0,02< | 0,19 + 0,025         |
| Tensile load, N: warpwise/fillingwise           | 380+25 | 260+20 | 210+20         |
| Count of cloth, strings/cm: warpwise/fillingwise| (22+1)/(13+1) | (16+1)/(8+1) | (10+1)/(8+1)         |
| Weave                                           | Sateen 5/3 | Standard |

The second important element are canvas (mates) based on basalt fiber (tabl. 3). Thermal insulating basalt canvas is essentially a mat with define geometrical dimensions, which is not sewed with a glass roving thread but holds its shape due to chaotically weaved fibres.
Table 3.

| Name of indicators                          | Density, kg/m³ |
|---------------------------------------------|----------------|
|                                             | 55            |
|                                             | 75            |
|                                             | 100           |
|                                             | 125           |
| Thermal conduction at 25 °C, not above, W/(m•K) | 0.038–0.039   |
|                                             | 0.040–0.041   |
|                                             | 0.041–0.043   |
|                                             | 0.045–0.050   |
| Field seal rate                             | 1.5           |
| Contractility, not above %                  | 35            |
|                                             | 25            |
|                                             | 15            |
| Tensile load, not less, N                   | 80            |
|                                             | 85            |
|                                             | 90            |
| Basalt fiber length, not above 800 mm; fiber diameter, 3-6 mm. Resilience, not less than 70%. Explavation temperature range from minus 169 to +750 °C (in the short run up to +900 °C). Manufactures’ length from 1500 to 3000; width 1000; thickness from 50 to 100 mm. Fireproofing basalt roll material is a canvas layer sewn together with a glass string using a sewing-knitting method (tabl. 4). Material is absolutely inert to acid, alkali, organic solvent; it doesn’t cause corrosion; its usage excludes flame spreading.

Table 4.

| Indicators                     | Mark of material |
|-------------------------------|------------------|
|                               | M-5  | M-8  | M-10 | M-13 | M-16 |
| Mass per area, g/m², not above| 500  |
| Thickness, mm                 | 5    |
| Thermal conduction, W/(m•K) at 25/125/300 °C | 0.033 / 0.045 /0.080 |

Building system supposes usage in structure materials having different properties. Herewith, materials disposal in a structure should ensure maximum of its operational characteristics and its durability. By reference to outlined requirements for enclosing structures of sea constructions for the polar region climate circumstances, a layer-like structure system was accepted (fig. 2).

A base of the system is a load-bearing framework made of a light steel thermal-insulating section (LST-section) made of a stainless steel or zinc-coated steel. An exterior (outside) sheathing is made of metal sheets (a stainless steel or zinc-coated steel with polymer coating) or a fiber-cement plates. An internal sheathing is made of gypsum-fiber waterproof sheets (GFWS) or water and fire resistant gypsum boards (GB-WF). Elements of external and internal sheathing are jointed with framework elements as well as ceiling and floor structures throughout anti-vibration pads made of several layers of basalt fiber BF-11. It is possible to arrange a ventilated airspace 10 mm wide between the external sheathing layer and the isolation system.

Platings of basalt fiber BF-13 are placed along the external perimeter of insulation covering as an additional element of fire and vibration protection. A major thermal resistance layer is the basalt canvas (tabl. 2) with a density 50-55 kg/m³. A canvas of 100 mm thick is laid in two layers between the elements of a load-bearing framework with butt joint overlapping. Fireproofing basalt roll material (tabl. 3) of 5-6 mm thick is on the internal side of isoulation system.
Figure 3. Scheme of an external partition in a living accommodation (framework elements are not shown): 1 – an exterior sheathing; 2 – a fireproofing material; 3 – a thermal resistance layer; 4 – an internal fireproofing material; 5 – an internal lining material; 6 – a ventilated airspace

Conducted test and computations show that this system allows to ensure the enclosing structure’s thermal resistance not less the $5 \text{ m}^2\cdot\text{°C}/\text{W}$ taking into consideration loss for window areas and dissimilarity for thermal bypasses. Base decision for internal partitions (division walls) is the same. In this case major aptitude criteria is noise and vibration isolation and fireproofing. Thermal insulation layer thickness is 50 mm. Common partition thickness is not above than 70 mm.

4. Conclusions

Wares based on basalt fiber offer a set of features which allow to recommend their usage in isolation systems of the projects disposed in the Arctic climate circumstances and where special claims of vibration and noise isolation as well as fireproofing are demanded.

Correcting mineral additives introduced into a working mass during its grinding have been developed. Introducing of the modifying additives into a working mass allows to reduce the optimal temperature range of working mass melting by 80–100 °C. The optimal amorphous degree of the melt is achieved in the modified working mass’ melting temperature range of 1400–1520 °C, which allows to reduce energy consumption during manufacturing and use advanced smelting units. Preserving of the acidity modulus of working mass without its significant changes is the reason why the performance characteristics of a fiber (in particular, their fire resistance, service durability and resistance in aggressive environments) will remain stable, as well as the properties of products based on this fiber.

Isolation system of the enclosing structures for the oil and gas platforms using materials which have fire resistance more than 750 °C allows providing external walls thermal resistance not less than $5 \text{ m}^2\cdot\text{°C}/\text{W}$.

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