Applied Engineering
2020; 4(2): 35-40
http://www.sciencepublishinggroup.com/j/ae
doi: 10.11648/j.ae.20200402.12

Innovative Energy Saving Sandwich Panels for Panel Housing

Nikolaev Valery Nikolaevich[1], Stepanova Valentina Fedorovna[2], Kozlov Vladimir Vladimirovich[3], Mikhailova Alyona Vladimirovna[1]

[1]ZAO "The Republican Chamber of Entrepreneurs", Cheboksary, Russian Federation

[2]Research Institute of Concrete and Reinforced Concrete Named After A. A. Gvozdev (NIIZHB), JSC "Research Center of Construction", Moscow, Russian Federation

[3]FSBI «Research Institute of Building Physics of the Russian Academy of Architecture and Building Sciences», Moscow, Russian Federation

Email address:

v.nikolaev@zaorpp.com (N. V. Nikolaevich), vfstepanova@mail.ru (S. V. Fedorovna), kozlov.v2@yandex.ru (K. V. Vladimirovich), a.mihajlova@sirep.ru (M. A. Vladimirovna)

[*]Corresponding author

To cite this article:

Nikolaev Valery Nikolaevich, Stepanova Valentina Fedorovna, Kozlov Vladimir Vladimirovich, Mikhailova Alyona Vladimirovna. Innovative Energy Saving Sandwich Panels for Panel Housing. *Applied Engineering.* Vol. 4, No. 2, 2020, pp. 35-40. doi: 10.11648/j.ae.20200402.12

Received: May 14, 2020; **Accepted**: July 20, 2020; **Published**: August 10, 2020

Abstract: Today large-panel house construction occupies a leading place, both in terms of speed of construction and in terms of sales, which contributes to an increase in the volume of prefabricated house-construction. Modern technologies allow creating comfortable, bright residential buildings of high quality. However, the issues of thermal insulation remain relevant: increased requirements for energy efficiency of residential facilities, new materials and construction technologies are being introduced. In the industrial construction market, metal diagonal ties and mounting loops of ferrous metal are widely used, which affects the energy efficiency of houses. Currently, in the technology of construction of panel houses of sandwich panels, current trend is to reduce the standard thickness of the facade layer of a three-layer sandwich panel (GOST 31310-2015) from 70 mm to 40 mm or less. The new materials proposed in the paper can reduce metal- and material consumption and improve the thermal characteristics of panel houses. The use of construction products made of composite materials such as diagonal flexible ties, composite flexible mounting loops and composite reinforcing mesh will allow increasing the energy efficiency of the panel, reducing the cost of manufacturing of the panel and increasing productivity – creating an innovative energy-efficient reinforced concrete sandwich panel of the 21st century. The paper is devoted to studying the effect of replacing steel flexible ties with composite ones, and replacing steel loops with flexible mounting loops in three-layer sandwich panels.

Keywords: Flexible Diagonal Ties, Mounting Loops, Composite Mesh, Facade Layer, Wall Concrete Three-Layer Panels, Energy Efficiency, Composite Materials

1. Introduction

The construction of houses using concrete three-layer wall panels with effective insulation is fast, reliable and year-round construction.

Reliability and energy efficiency of panel houses directly depend on the characteristics of the materials of which the panels are made.

Proposed in the 70s Peikko's stainless steel diagonal flexible ties do not fully meet energy efficiency requirements. These products are widely used to this day.

Large developers in Russia, such as company group «PIK», «LSR», «Leader Prom» LLC use steel flexible ties and mounting loops of ferrous metal in construction. Abroad, these products are also actively used in construction.

It is believed that steel flexible ties and mounting loops made of ferrous metal slightly affect the thermal properties of the panel and the entire building.

The article is devoted to the study of the effect of replacing steel flexible ties with composite ones, and replacing steel loops with flexible mounting loops in three-layer sandwich panels.

The use of composite building products such as composite flexible diagonal ties SIREP, flexible mounting loops SIREP, reinforcing composite mesh for thin-walled facade SIREP will increase thermal properties and create an innovative energy-efficient reinforced concrete sandwich panel.

2. Composite Flexible Diagonal Connections SIREP

Figure 1 shows composite flexible diagonal ties SIREP [2, 3].

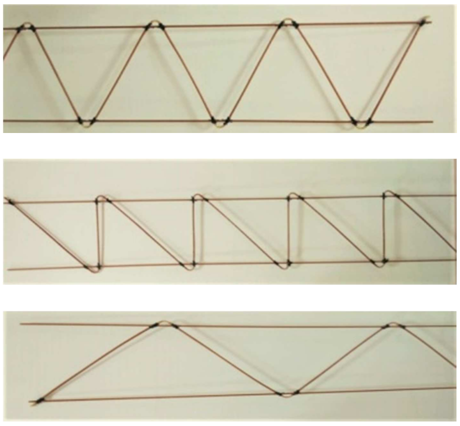

Figure 1. *Composite flexible diagonal ties.*

Composite diagonal flexible tie SIREP is a frame of two parallel straight rods, fastened together by a zigzag rod using plastic connecting elements, which provides constructive interaction between all layers of the sandwich panel at various loads and displacements.

This development belongs to ZAO "The Republican Chamber of Entrepreneurs", which has significant practical experience in the development and production of composite products for the construction industry.

The reliability and effectiveness of the use of composite diagonal flexible connections is confirmed in the framework of the tests. Samples of the 3NSg09.23.32 external wall panel with composite diagonal flexible connections SIREP were made, one of which was tested for shear of the outer layer relative to the inner layer under vertical load at Research Institute of Moscow Construction, and the other for determining the fire resistance at the Test Center "Fire Resistance" (Figure 2).

Figure 2. *Fragment of a three-layer outer wall panel with composite flexible diagonal tiess during shear tests.*

The test results confirmed the reliability of SIREP composite diagonal flexible connections [3]. The high quality of products and their suitability was confirmed by the Ministry of Construction and Housing and Communal Services of Russia: technical certificate No. 5592-18 was issued.

3. Mounting Loops SIREP

When carrying out loading and unloading and installation operations, ferrous metal mounting loops are used, manufactured in accordance with TR 94-2003 "Sling loops of prefabricated concrete and reinforced concrete structures, design, calculation and testing". The design decisions stipulate that the loop after installing reinforced concrete sandwich panels manufactured in accordance with Interstate Standard 31310-2015 "Three-layer reinforced concrete wall panels with effective insulation" must be cut, however, this operation is not performed in construction practice due to the complexity of execution and fire hazard (when using a gas cutter or grinder, red-hot metal particles can cause the foam to ignite). In addition, there is currently no effective way to control these works on cutting a metal loop. The pits are monolithic with concrete, the metal loop remains in the panel as a cold bridge, which leads to a decrease in energy-saving properties of panels and the entire building under construction as a whole [3].

Flexible mounting hinge SIREP (hereinafter referred to as FMH) is a more perfect alternative to steel hinges [3]. SGP is a product that is made of textile tape for slings connected by longitudinal seams and equipped with 4 anchors (Figure 3).

Figure 3. *Mounting Loop SIREP.*

Anchors are pieces of fiberglass reinforcement [4].

Flexible mounting loops SIREP have proven their reliability in practice: sandwich panels are formed using FMH in «SiB-Center», St. Petersburg (Figure 4).

Figure 4. *FMH in working straightened form, «SiB-Center», St. Petersburg.*

The need for mounting flexible hinges was caused by the requirement of increased heat-shielding characteristics of the panels and their temperature uniformity [5]. These panels were made for the construction of private cottages, whose customers, when accepting housing, control the presence of cold bridges using thermal imaging, which encouraged developers to use SIREP flexible mounting loops and eliminate the appearance of cold bridges.

In addition, the use of flexible mounting loops allows to reduce the thickness of the facade layer of the panel, which is complicated by the use of metal loops.

4. Calculations of the Effect of Replacing Steel Products with Composite Ones

When calculating the effect of replacing steel flexible ties and loops with composite flexible diagonal connections and flexible mounting loops, the panel was 330 mm thick, where the inner concrete layer was 80 mm, the thermal insulation layer PPS25 was 170 mm, the outer concrete layer was 80 mm (Figure 5).

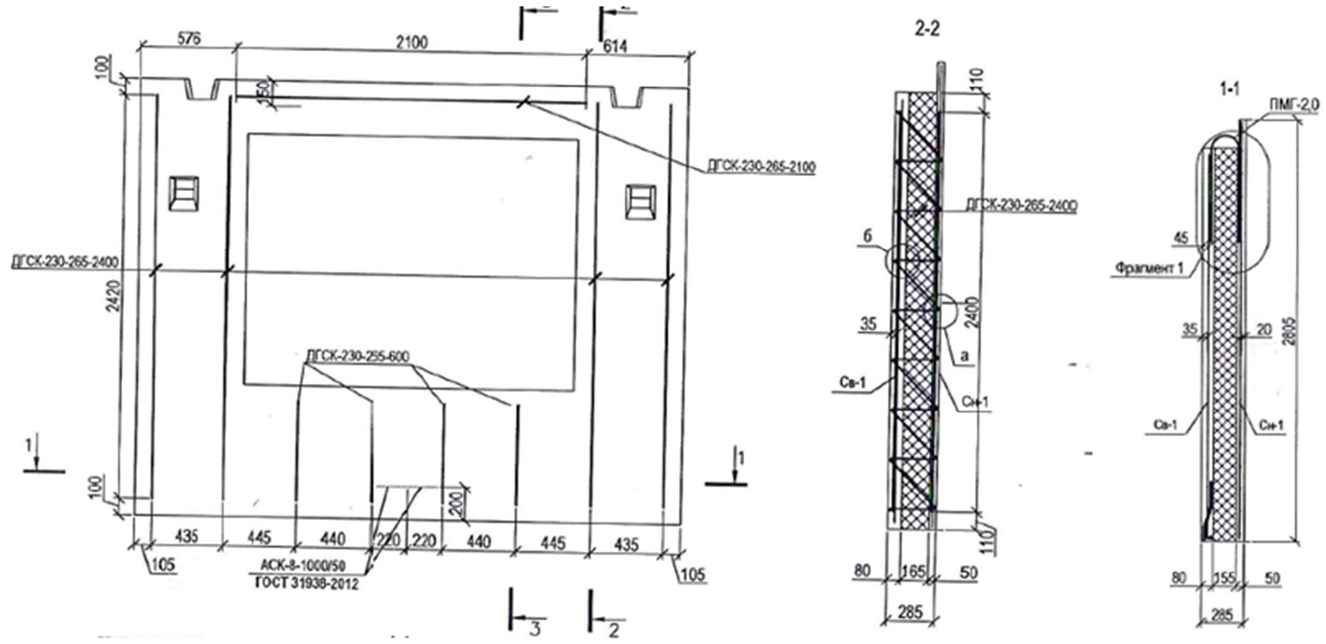

Figure 5. *Drawing of the panel.*

The thermal characteristics of the panel manufactured according to the Interstate Standard GOST 31310-2015 are presented in Table 1. The influence of flexible connections and hinges on the thermal characteristics of the panel consists of four lines of the table, designated as “flexible connections 1, 2, 3” and “steel loops”.

Table 1. *Thermotechnical characteristics of the panel.*

Design element	Specific Geometric Index	Specific Heat Losses	Specific heat flux due to element, Wt/(m^2 °C)	Share of total heat flux, %
Smooth wall	a1=1 m^2/m^2	U_1=0,258 Wt/(m^2 °C)	U_1a_1=0,258	79,6
Horizontal joint	l1=0,51 m/m^2	Ψ_1=-0,004 Wt /(m °C)	$\Psi_1 l_1$=-0,002	-0,6
Vertical joint	l2=0,4 m/m^2	Ψ_2=-0,007 Wt /(m °C)	$\Psi_2 l_2$=-0,003	-0,9
Window block adjacency	l3=1,0 m/m^2	Ψ_3=0,007 Wt /(m °C)	$\Psi_3 l_3$=0,007	2,2
Flexible connections 1	n1=0,57m/m^2	χ_1=0,048 Wt /(m °C)	$\chi_1 n_1$=0,027	8,3
Flexible connections 2	n2=0,43m/m^2	χ_2=0,012 Wt /(m°C)	$\chi_2 n_2$=0,005	1,5
Flexible connections 3	n3=0,43m/m^2	χ_3=0,028 Wt /(m °C)	$\chi_3 n_3$=0,012	3,7
Steel hinges	n4=0,28m/m^2	χ_4=0,07 Wt /(m °C)	$\chi_4\ n_4$=0,02	6,2
Total			$1/R^{pr}$=0,324	100

Specific heat losses for flexible ties are calculated according to Clause G. 7 of SP 230.1325800.2015. Table D. 41 SP 230.1325800.2015 gives the dependence of the specific heat loss on the cross-sectional area of steel reinforcement. Considering the thermal conductivity of composite flexible ties, their characteristic values do not fall into table D. 41, since they are too small. However, it can be noted that for small cross sections of flexible ties (similarly for small thermal conductivities), the change in the specific heat loss occurs almost linearly with a change in the cross section or thermal conductivity. More precisely, in this case, the effect on the heat loss of flexible bonds will change when replacing steel ties with composite ones in proportion to the change in thermal conductivity with a coefficient of 0.9. If some parts of the initial ties were made of non-corrosion-resistant steel, such estimate will be an upper estimate, since the thermal conductivity of the non-corrosion-resistant steel is several times higher.

Since the general arrangement and shape of the ties practically do not change, but the material and the thermal conductivity do, the total effect of all ties should be recalculated:

$$\chi_1 n_1 + \chi_2 n_2 + \chi_3 n_3 = 0{,}027 + 0{,}005 + 0{,}012 = 0{,}044 \text{ Wt/(m}^2\ {}^\circ\text{C)} \quad (1)$$

The conversion factor (thermal conductivity ratio with a coefficient of 0.9) is approximately 30 times.

After replacing the corrosion-resistant ties with composite ties, the total effect of all ties will be the following:

$$\chi_1 n_1 + \chi_2 n_2 + \chi_3 n_3 = 0{,}0015 \text{ Wt/(m}^2\ {}^\circ\text{C)} \quad (2)$$

Currently, when calculating the specific heat flux, it is customary to take into account only three decimal places, so even an error of 20% would not be noticeable and would not affect the reduced total thermal resistance.

The effect of flexible mounting loops is even smaller and can be ignored.

The calculations of the reduced total thermal resistance of the panel with composite flexible ties and flexible lifting loops are summarized in table 2.

Table 2. *Calculations of reduced total thermal resistance of a panel with composite flexible connections and flexible mounting loops*

Design element	Specific Geometric Index	Specific Heat Losses	Specific heat flux due to element, Wt/(m² °C)	Share of total heat flux, %
Smooth wall	$a1=1$ m²/m²	$U_1=0{,}258$ Wt/(m² °C)	$U_1a_1=0{,}258$	98,7
Horizontal joint	$l1=0{,}51$ m/m²	$\Psi_1=-0{,}004$ Wt /(m °C)	$\Psi_1 l_1=-0{,}002$	-0,8
Vertical joint	$l2=0{,}4$ m/m²	$\Psi_2=-0{,}007$ Wt /(m °C)	$\Psi_2 l_2=-0{,}003$	-1,2
Window block adjacency	$l3=1{,}0$ m/m²	$\Psi_3=0{,}007$ Wt /(m °C)	$\Psi_3 l_3=0{,}007$	2,7
Flexible connections 1	$n1=0{,}57$m/m²		0,0015	0,6
Flexible connections 2	$n2=0{,}43$m/m²			
Flexible connections 3	$n3=0{,}43$m/m²			
FMH			$\chi_4 n_4=0{,}0$	0,0
Total			$1/R^{pr}=0{,}2615$	100

The reduced total thermal resistance of the panel is:

$$R_{\text{st}}^{\text{pr}} = \frac{1}{0{,}2615} = 3{,}82 \text{ (m}^2\cdot{}^\circ\text{C)/Wt} \quad (3)$$

The given thermal resistance is much higher than the requirements for Moscow (in SP 50.13330.2012, where thermal resistance is 2.99 (m²·°C)/Wt).

The heat transfer performance uniformity factor of the panel is 0.99. This is a very high value.

Since the obtained reduced heat transfer resistance of the panel is much higher than the required one, the question is how much the insulation thickness can be reduced, while remaining within the required values.

The maximum specific heat flux that meets the requirements for reduced heat transfer resistance in Moscow is:

$$\frac{1}{2{,}99} = 0{,}3345 \text{ Wt/(m}^2\cdot{}^\circ\text{C)} \quad (4)$$

The difference between the specific heat flux obtained in the calculations and the maximum allowable can be compensated by changing the thickness of the insulation. This difference is 0,073 Wt/(m²·°C).

$$0{,}3345 - 0{,}2615 = 0{,}073 \text{ Wt/(m}^2\cdot{}^\circ\text{C)} \quad (5)$$

Thus, the heat transfer resistance along the surface of the structure can be reduced to 3.02 (m²·°C)/Wt.

$$R_{o2} = \frac{1}{0{,}258 + 0{,}073} = 3{,}02 \text{ (m}^2\cdot{}^\circ\text{C)/Wt} \quad (6)$$

Thus the minimum thickness of insulation in the panels can be found.

When using expanded polystyrene with a thermal conductivity of 0.044 Wt/(m°C), the minimum required insulation thickness is 130 mm.

$$R_{o1} = \frac{1}{8{,}7} + \frac{0{,}08}{2{,}04} + \frac{0{,}13}{0{,}044} + \frac{0{,}08}{2{,}04} + \frac{1}{23} = 3{,}19 \text{ (m}^2\cdot{}^\circ\text{C)/Wt} \quad (7)$$

The reduced heat transfer resistance is 3,15 (m²·°C)/Wt.

When using polystyrene foam with a thickness of 145 mm, the heat transfer resistance along the surface of the structure will be 3,53 (m²·**°C**)/Wt

$$R_{o1} = \frac{1}{8{,}7} + \frac{0{,}08}{2{,}04} + \frac{0{,}145}{0{,}044} + \frac{0{,}08}{2{,}04} + \frac{1}{23} = 3{,}53 \text{ (m}^2\cdot{}^\circ\text{C)/Wt.} \quad (8)$$

The reduced heat transfer resistance of the panels is 3,49 (m²·°C)/Wt.

It can be seen from the above calculations that when using composite products, the heat loss of the panel is negligible (0.6%) in comparison with the heat loss of the panel with metal products (23.5%).

5. Reinforcing Composite Mesh for Thin-walled Facade SIREP

After The front layer of the sandwich panel performs a protective and decorative function and is not a supporting element. According to Interstate Standard 31310-2015, the thickness of the facade layer reinforced with a metal reinforcing mesh of rods with a diameter of 5 mm is 70-80 mm, which significantly increases the weight of the panel. Reducing the thickness of the facade layer requires a strict arrangement of the metal mesh in the middle of the thickness of the concrete layer, which is achieved using a large number of special clamps. The installation of clamps is a separate technological operation, which requires a large amount of manual labor and requires careful monitoring. In order to increase energy saving, house-building factories in Belarus produce sandwich panels whose front layer thickness is 50 mm, however, another problem may arise - the formation of corrosion traces on the facade of buildings.

In order to solve these problems, ZAO "The Republican Chamber of Entrepreneurs" offers a SIREP composite mesh for a thin-walled facade layer, at the intersection of which there are plastic connecting elements with an upper and lower "leg" of thermoplastic material (for example, polyethylene, polypropylene) in the form of truncated cones up to 10 in length -25 mm (Figure 6).

(a)

(b)

Figure 6. *Composite mesh SIREP for facade layer.*

Due to the "legs" it becomes possible to install the reinforcing mesh in the desired section of the concrete layer, and after the concrete has hardened, it is firmly fixed in its thickness. "Legs" are a structural element of the reinforcing mesh, which excludes the technological operation of their installation, as well as control of their installation. This significantly reduces the amount of manual labor and increases the productivity of the manufacture of sandwich panels. This design of the composite mesh allows to reduce the thickness of the concrete facade layer of the panel from 70 mm to 40 mm, thereby increasing the insulation layer by 30 mm while maintaining the overall thickness of the sandwich panel. The composite mesh construction is durable and can withstand the weight of an adult (Figure 7).

(a)

(b)

Figure 7. *Composite mesh SIREP for facade layer under adult weight.*

6. Conclusions

Thus, the calculations performed in the paper showed that steel flexible ties and mounting loops made of ferrous metal reduce the heat resistance of the wall by 23.5%, which is fundamentally different from the current opinion about the insignificant effect of metal products on the heat-shielding properties of the panel and the whole building.

Using the proposed technical solution – composite flexible diagonal ties SIREP, flexible mounting loops SIREP, reinforcing composite mesh for thin-walled facade SIREP will allow creating a highly cost-effective innovative energy-efficient reinforced concrete sandwich panel of the 21st century with a thinner facade layer.

It may be noted that these products are new products in the construction market. The use of these products allows solving a number of problems of modern panel housing construction:

1. to increase the energy efficiency of the panel by 23.5% through the use of composite diagonal flexible ties and mounting loops SIREP;
2. to reduce the cost of manufacturing the panel due to the lower price of composite diagonal flexible ties are 2 times lower than metal ones);
3. to increase the productivity of manufacturing panels through the use of composite mesh SIREP and flexible mounting loops.

References

[1] Zayavka na izobretenie GB № 2164367 (A). A concrete building unit of a sandwich structure / Paakkinen Ilmari, Partek AB. Published 19. 03. 1986. (In UK).

[2] Patent RF 149446. Gibkaya svyaz’ dlya trekhslojnyh ograzhdayushchih konstrukcij [Flexible connection for three-layer walling]. Gibkaya svyaz’ dlya trekhslojnyh ograzhdayushchih konstrukcij. Declared 15.07.2014. Pub-lished 10.01.2015. Bulletin No. 1. (In Russian).

[3] Stepanova V. F., Nikolaev V. N., A new level of panel housing construction: composite diagonal flexible ties and flexible mounting loops for three-layer concrete panels. Zhilishchnoe Stroitel’stvo [Housing Construction]. 2019. No. 10, pp. 14–20. (In Russian).

[4] Utility Model Patent 194846. Montajnaya petlya [Mounting loop]. Priority 27.08.2018. (In Russian).

[5] Gagarin V. G., Dmitriev K. A. Accounting for thermal engi-neering heterogeneity in the assessment of thermal protec-tion of enclosing structures in Russia and European coun-tries. Stroitel’nye Materialy [Construction Materials]. 2013. No. 6, pp. 14-16. (In Russian). Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, “Electron spectroscopy studies on magneto-optical media and plastic substrate interface,” IEEE Transl. J. Magn. Japan, vol. 2, pp. 740–741, August 1987 [Digests 9th Annual Conf. Magnetics Japan, p. 301, 1982].

[6] Babkov V. V., Kolesnik G. S., Gajsin A. M. i dr. Bearing exter-nal three-layer walls of buildings with high thermal protec-tion. Stroitel’nye Materialy [Construction Materials]. 1998. No. 6, pp. 16–18. (In Russian).

[7] Stepanova V. F., Buchkin A. V., Iurin E. U., Nikishov E. I., Ishchuk M. K., Granovskii A. V., Dzhamuev B. K., Aiziatullin Kh. A. Composite polymer mesh for stone masonry. Stroi-tel’nye Materialy [Construction Materials]. 2019. No. 9, pp. 44–50. (In Russian). DOI: https://doi.org/10.31659/0585-430X-2019-774-9-44-50.

[8] Rozental’ N. K., CHekhnij G. V., Bel’nik A. R., ZHilkin A. P. Corrosion resistance of polymer composites in the alkaline environment of concrete. Beton i zhelezobeton. 2002. No. 3, pp. 20–23. (In Russian).

[9] Stepanova V. F., Stepanov A. Yu., Zhirkov E. P. Armatura kompozitnaya polimernaya [Composite polymer reinforce-ment]. Moscow: ASV. 2013. 200 p.

[10] Savin V. F., Blaznov A. N., Bashara V. A., Lugovoj A. N. EHk-spress-metod ocenki stojkosti polimernyh kompozicionnyh materialov k vozdejstviyu shchelochnoj sredy. Tekhnika i tekh-nologiya proizvodstva teploizolyacionnyh materialov iz miner-al’nogo syr’ya [Express method for assessing the resistance of polymer composite materials to the effects of an alkaline environment. Technique and technology for the production of thermal insulation materials from mineral raw materials]: Doklad VI Vserossijskoj nauchno-prakticheskaya konferenci-ya. Moscow: FGUP «CNIIHM». 2006. pp. 203–207.

[11] Nikolaev S. V. Modernization of large-panel housing con-struction - the locomotive of low-cost housing construction. Zhilishchnoe Stroitel’stvo [Housing Construction]. 2011. No. 3, pp. 3–7. (In Russian).

[12] Stepanova, V. F. Protection of concrete and reinforced concrete structures from corrosion - the basis of ensuring the durability of buildings and structures. Promyshlen-noe i grazhdanskoe stroitel’stvo. 2013. No. 1, pp. 13–16. (In Russian).

[13] Aslanova, L. G. Usloviya primeneniya stekloplastikovoi armaturi v izgibaemih betonno-polimernih konstrukciyah elektrosetevogo stroitelstva: dissertaciya kand. tehn. nauk. [Conditions for the use of fiberglass reinforcement in flexible polymer-concrete structures of electric grid construction: PhD thesis] – M.: NIIJB. – 1983.

[14] Gorb A. M., Vojlokov I. A. The fiber-reinforced concrete – background, regulatory framework, problems and solu-tions. Mezhdunarodnoe analiticheskoe obozrenie. 2009. No. 2, pp. 1–4. 1http://www. monolitpol. ru/files/monolit-pol026. pdf (Date of access 14. 04. 2018). (In Russian).

[15] Stepanova V. F., Falikman V. R., Buchkin A. V. Tasks and prospects of application of composites in construction. Ac-tual questions of theory and practice of application of com-posite reinforcement in construction: Collected materials of the Third Scientific and Technical Conference. Izhevsk. 2017, pp. 55–72. (In Russian).