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Steel profile corrosion resistance in contact with monolithic foam concrete

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Abstract. The study evaluates corrosion resistance of steel profiles in contact with monolithic foam concrete with a thickness of 5 and 10 mm. There are two types of samples: structural steel ones and cold-formed galvanized steel ones. A visual examination of samples exposed to high temperature and relative humidity is carried out. The corrosion resistance of profiles made of structural steel and cold-formed galvanized steel in full contact with monolithic foam concrete provides. Metal passivation (formation of a protective film) occurs due to the high alkalinity of foam concrete. The pH values of concrete and concrete mixture, experimentally obtained, vary in the range of 12.18 ... 12.36 at all stages of the structural behavior. This indicates a favorable highly alkaline environment for profile steel.

1 Introduction

Lightweight steel concrete structures (LSCS) c consist of steel profile (profile steel frame) with a monolithic foam concrete and panel sheathing [1].

There are two types of profile steel frames for lightweight steel concrete structures. The first type is cold-formed galvanized steel profile (frame of light-gauge steel structures) and the second type is structural steel (rolled steel).

Monolithic foam concrete is used for enclosure structures in the form of lightweight steel concrete structures [2, 3] and backfill materials for highways [4], railways, plazas [5].

Foam concrete has several advantages over other structural and insulating materials. It is characterized by a low density, good sound insulating properties, and high thermal insulation capacity, while it exhibits sufficient compressive strength for the load-bearing function [6, 9].

There are additives for foam concrete, such as fly ash [10-12] metakaolin [10, 13], shredded rubber [14, 15] silica fume [16, 17], granulated blast furnace slag [18, 19], which can improve the concrete properties.

The foam concrete considered in this work is made using a protein foaming agent [20, 21].

There are researches devoted to the study of the properties of thermal properties [2], strength characteristics [1, 22], and fire resistance [23, 24] of these structures.

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The work [2] shows the experimentally obtained value of thermal conductivity resistance of enclosure structure from thin-wall profiles with foam concrete. It is 1.367 ($m^2 \cdot K$)/W, taking into account thermal resistance 0.783 ($m^2 \cdot K$)/W for reinforced sections.

The work [1] experimentally proves that the foam concrete, despite its own extremely low strength class, actually includes in the operation, preventing such effects as stability local loss, crushing and profile steel elements cross-section warping and increases the slabs overall load capacity by 20-25%., which corresponds to a condition load effect factor of at least 1.2…1.25.

The researches [23, 24] provide information about fire resistance lightweight steel concrete structures, composed of profiled steel filled with a monolithic foam concrete with a 200 kg/m^3 - 400 kg/m^3 density, and with fiber cement sheets sheathing. The actual fire resistance limit of samples of the wall panel fragment is REI 60 with a uniformly distributed load of 20 kN/m [23]. Actual fire resistance limit of samples of the slab panel fragment at least REI 60 with a uniformly distributed load of 4 kN/m^2 [24].

However, there are no studies of the corrosion resistance of profile steel, which is part of the lightweight steel concrete structures, in contact with lightweight foam concrete based on a protein foaming agent.

This work aims to experimentally study the corrosion resistance of ferrous and galvanized steel profiles in contact with lightweight foam concrete at high temperature and relative humidity.

Tasks of the research:

1. Testing of structural steel samples filled with monolithic foam concrete in the temperature humidity test chamber.
2. Testing of cold-formed galvanized steel C-stud samples filled with monolithic foam concrete in the temperature humidity test chamber.
3. Measurement of the pH values (pH) of foam concrete mixture and foam concrete.

2 Materials and Methods

a. Lightweight steel concrete structures materials

For the production of lightweight steel concrete structures, the following materials were used:

1. Monolithic foam concrete with a density of 200 kg/m^3 (D200). Concrete mixtures are presented in Table 1.

Table 1. Concrete mixtures

Cement (kg/m^3)	Sand (kg/m^3)	Water (kg/m^3)	Foam (l/m^3)
170	-	77	890

Concrete mixing design to obtain samples of monolithic foam concrete "SOVBI" was carried out following the standard STO 06041112.002-2018 "Panels from steel concrete structures based on heat-insulating non-autoclave monolithic foam concrete, profile steel faced with fibrocement sheets". The concrete mixture was prepared using the SOVBI technology using a foam generator and a gerotor pump.

2. Structural steel. A closed rectangular cut profile 100 x 50 x 3 mm with a length of 50 mm. The section is filled with a layer of foam concrete of 5 - 10 mm thick (see Figure 2).
3. Galvanized cold-formed steel C-studs 100 x 50 x 1.5 mm with a length of 50 mm. The section is filled with a layer of foam concrete of 5 - 10 mm thick (see Figure 3).

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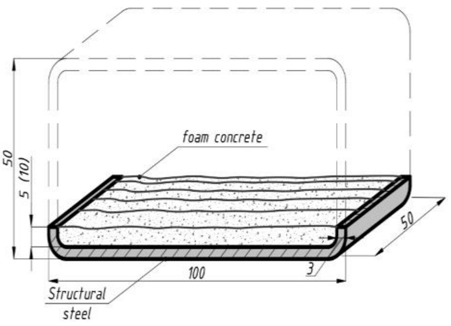

Fig. 1. Scheme of samples from structural steel profiles for testing.

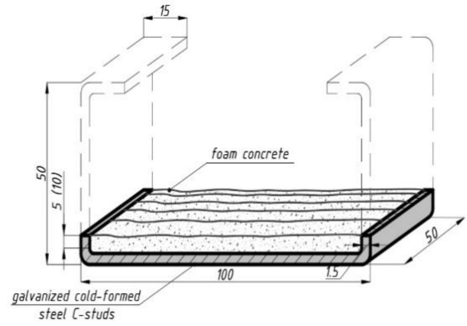

Fig. 2. Scheme of samples from galvanized cold-formed steel C-studs for testing.

b. Testing of samples in the temperature humidity test chamber

Samples in the form of cut profiles filled with foam concrete were made for testing. Samples were 10 copies of structural steel and 10 copies of galvanized cold-formed steel C-studs. Both versions of the samples had two varieties: samples with dimensions of 50x100x5 mm (5 copies) and samples with dimensions of 50x100x10 mm (5 copies).

Before testing, the edges and the back of the samples were sealed.

Figure 3 shows a sample prepared for testing.

The duration of the tests was 10 days with an intermediate extraction of samples on the 5th day. The studies were carried out in the temperature humidity test chamber CM - 70 / 100-1000 TBX at a temperature of + 35 ± 3 °C and relative humidity of 95%.

Samples during testing are shown in Figure 4.

Fig. 3. Sample for testing.

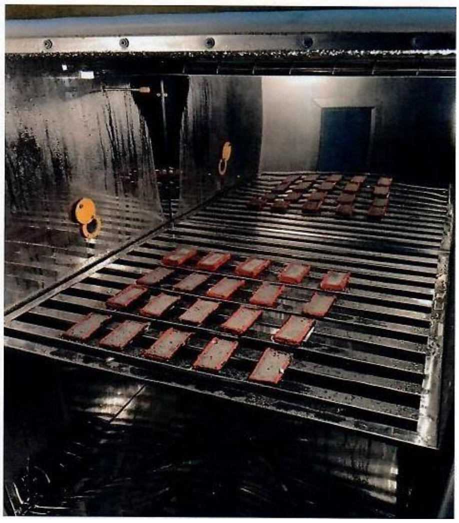

Fig. 4. Samples during testing.

After testing, the samples were dried at a temperature of 22 °C, relative humidity of 45% for five hours. Further, a visual assessment of the foam concrete surface state for the presence of corrosion damage was carried out. At the final stage of the assessment, the foam concrete was removed and a visual examination of the surface of the profiles was carried out. The moisture penetration was recorded by the presence of corrosion products. An indicator of corrosion processes for galvanized profiles is zinc oxide, which is present in the form of white corrosion products. An indicator of corrosion processes for profiles made of structural steel is iron oxides, represented by red corrosion products.

3 Results and Discussion

a. Visual examination of samples

A visual examination was carried out after testing. Corrosion products along the edge of the structural steel samples were found. The reason for this was the distance between the profile and the foam concrete where moisture penetrated. Corrosion products were also present on the body of some samples.

Figures 5 and 6 shows an example of structural steel samples with removed foam concrete after testing.

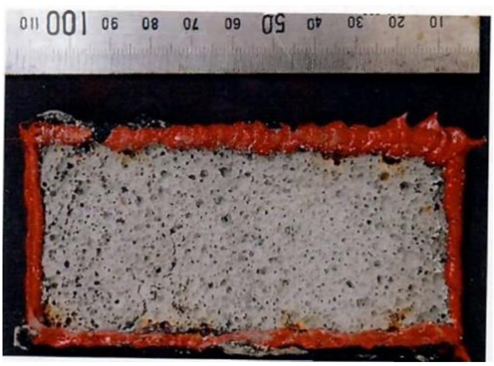

Fig. 5. Tested structural steel sample before removing foam concrete.

Fig. 6. Tested structural steel sample after removing foam concrete.

The difference between the samples taken out after 5 and 10 days of testing was visually noticeable on galvanized steel samples.

Figure 7 shows galvanized steel samples with different exposure times in the temperature humidity test chamber. White deposits on samples are corrosion products - zinc oxide.

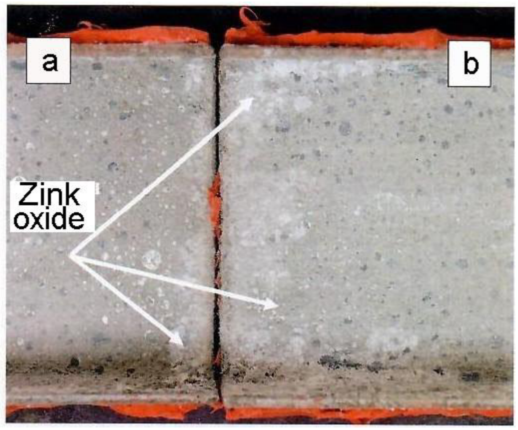

Fig. 7. Tested cold-formed galvanized steel C-stud sample a) after 5 days of testing b) after 10 days of testing.

Propagation of corrosion processes from the profile wall was observed on all samples.

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The test results showed that all samples had corrosion products at the edges. The body of the galvanized steel samples did not have any individual corrosion products. The body of three structural steel samples with a thickness of 5 mm had corrosion products.

Figure 8 shows the corrosion damage of structural steel samples after testing.

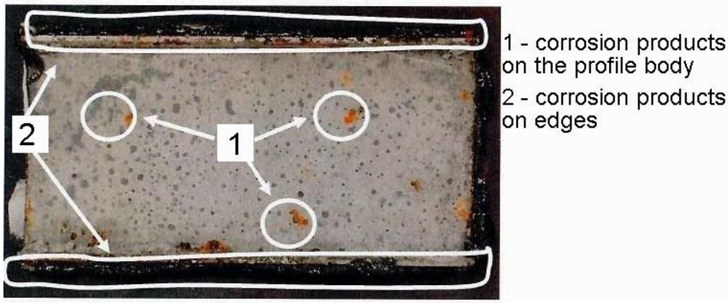

Fig. 8. Structural steel samples with removed foam concrete after testing.

White deposits on the tested samples indicate white rust, which occurs in a highly alkaline environment and indirectly indicates the formation of a protective film on the metal surface. This film inhibits the development of other types of water-induced corrosion.

In terms of corrosion resistance, zinc has a higher degree of corrosion protection than carbon steel. Its use is preferable in atmospheric corrosion conditions.

b. Results of the pH measurements

The pH value measurement of foam concrete mixture and the measurement of the pH value of foam concrete samples were carried out.

The pH value measurement of foam concrete mixture is shown in Figure 9. The pH value measurement of foam concrete is shown in Figure 10.

Fig. 9. pH measurements of foam concrete mixture.

Fig. 10. pH measurements of foam concrete.

The pH value of the foam concrete mixture was 12.36. The pH value of the foam concrete was 12.18.

According to the results of the comparison of the measurement data, it can be said that the pH value practically did not change during the test. The measurements were carried out in equal volumes of foam concrete.

Comparison of measurements shows that the pH value practically did not change during the tests. The measurements were carried out in equal volumes of foam concrete.

A highly alkaline environment was formed because the pH at all stages of modeling the structural behavior was significantly higher than 9. This environment was favorable for both steel and galvanized coatings.

4 Conclusions

Tests of steel samples, filled with foam concrete based on an organic foaming agent with a filling thickness of 5 mm and 10 mm were carried out. Samples were made from structural steel and cold-formed galvanized steel. A visual examination of samples exposed to high temperature and relative humidity was carried out.

From this research, the following conclusions can be obtained:

1. The corrosion resistance of profiles made of structural steel and cold-formed galvanized steel in full contact with monolithic foam concrete provides.
2. Metal passivation (formation of a protective film) occurs due to the high alkalinity of foam concrete.
3. To increase the corrosion resistance of profiles made of structural steel, it is recommended to apply a primer. It is recommended to apply the first coat of primer by spraying to prevent the formation of pores and bubbles on the surface.
4. The pH values of concrete and concrete mixture, experimentally obtained, vary in the range of 12.18 ... 12.36 at all stages of the structural behavior. This indicates a favorable highly alkaline environment for profile steel.

In the future, it is advisable to test metal profiles in contact with concretes based on other innovative components, for example, cold-bonded fly ash aggregate [25].

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References

1. Rybakov V.A. Condition Load Effect Factor of Profile Steel in Lightweight Steel Concrete Structures; Construction of Unique Buildings and Structures **89**, p. 8907 (2020)
2. Rybakov V.A., Ananeva I.A., Pichugin E.D., and Garifullin M. Heat protective properties of enclosure structure from thin-wall profiles with foamed concrete. Mag. Civ. Eng. **94**, pp. 11–20 (2020)
3. Rybakov V., Seliverstov A., Petrov D., Smirnov A., and Volkova A., Lightweight steel concrete structures slab panels load-bearing capacity MATEC Web Conf. **245**, (2018)
4. Cao H. Analysis of mechanical properties of transition segment of road and bridge based on high-strength foam concrete Frat. ed Integrita Strutt. **13**, pp.831–839 (2019)
5. Song Z, Lu Z and Lai Z The effect of lithium silicate impregnation on the compressive strength and pore structure of foam concrete Constr. Build. Mater. **277**, (2021)
6. Fediuk R., Amran M., Vatin N., Vasilev Y., Lesovik V., and Ozbakkaloglu T. Acoustic Properties of Innovative Concretes: A Review Materials (Basel). **14**, p.398 (2021)
7. Mechtcherine V., Markin V., Will F., Näther M., Otto J., Krause M., Nerella V. N., and

Schröfl C, Production of monolithic, load-bearing, heat-insulating wall structures by additive manufacturing with foam concrete Bauingenieur **94,** pp.405–415 (2019)

8. Sherbin S. A., and Gorbach P. S. Foam concrete production with addition of microsilica IOP Conf. Ser. Mater. Sci. Eng. **880,** (2020)
9. Lesovik V., Voronov V., Glagolev E., Fediuk R., Alaskhanov A., Amran Y. H. M., Murali G., and Baranov A. Improving the behaviors of foam concrete through the use of composite binder J. Build. Eng. **31,** (2020)
10. Deepak N., Thiagu H., and Manivel S. Study on strength of metakaolin based foamed concrete under different elevated temperature ARPN, J. Eng. Appl. Sci. **14**, pp.2980–2986, (2019)
11. Vatin N., Barabanshchikov Y., Usanova K., Akimov S., Kalachev A., and Uhanov A. Cement-based materials with oil shale fly ash additives. IOP Conf. Ser. Earth Environ. Sci. **578**, (2020)
12. Lesovik V., Glagolev E., Voronov V., Zagorodnyuk L., Fediuk R., Baranov A., Alaskhanov A., and Svintsov A. Durability behaviors of foam concrete made of binder composites Mag. Civ. Eng. **100**, (2021)
13. Deepak N, Thiagu H., and Manivel S. Study on strength of metakaolin based foamed concrete under different elevated temperature **14**, (2019)
14. Benazzouk A, Douzane O, Mezreb K and Quéneudec M Physico-mechanical properties of aerated cement composites containing shredded rubber waste Cem. Concr. Compos. **28**, pp.650–657, (2006)
15. Eltayeb E, Ma X, Zhuge Y, Youssf O and Mills J E 2020 Influence of rubber particles on the properties of foam concrete J. Build. Eng. 30 101217
16. Koksal F, Sahin Y and Gencel O. Influence of expanded vermiculite powder and silica fume on properties of foam concretes Constr. Build. Mater. **257**, (2020)
17. Barabanshchikov Y, Usanova K, Akimov S, Uhanov A and Kalachev A. Influence of electrostatic precipitator ash “zolest-bet” and silica fume on sulfate resistance of Portland cement Materials (Basel). **13,** pp.1–13 (2020)
18. Oren O H, Gholampour A, Gencel O and Ozbakkaloglu T. Physical and mechanical properties of foam concretes containing granulated blast furnace slag as fine aggregate Constr. Build. Mater. **238**, (2020)
19. Barabanshchikov Y, Usanova K, Akimov S and Bílý P. Low heat concrete with ground granulated blast furnace slag IOP Conf. Ser. Mater. Sci. Eng. **896**, (2020)
20. Kuzielová E, Pach L and Palou M. Effect of activated foaming agent on the foam concrete properties Constr. Build. Mater. **125**, (2016)
21. Montayev S A, Shakeshev T, Muratbai Z, Ryskaliyev N, Bolatovna A, Narikov K A, Khan Z and Kazakhstan W. Collagen agent technology for foam concrete production **12**, (2017)
22. Prabha P, Palani G S, Lakshmanan N and Senthil R. Flexural Behaviour of Steel-Foam Concrete Composite Light-Weight Panels KSCE, J. Civ. Eng. **22**, 3534–3545 (2018)
23. Rybakov V, Seliverstov A and Urmanceva K. Lightweight steel-concrete wall bearing structures under high-temperature exposure. Lect. Notes Civ. Eng. (2021)
24. Rybakov V, Seliverstov A and Urmanceva K. Fire resistance of lightweight steel-concrete slab panels under high-temperature exposure. (2021)
25. Usanova K.Y. Properties of Cold-Bonded Fly Ash Lightweight Aggregate Concretes Lect. Notes Civ. Eng. **70**, 507–516 (2020)