UDC 624.94.014.2:693.972 **doi:10.31650/2707-3068-2025-29-41-46**

FIRE RESISTANCE OF COLD FORMED STEEL FRAMES OF 3D-VOLUMETRIC MODULES IN COMPARISON WITH ROLLED STEEL PROFILES

Maslyanenko Y.V., PhD (Tech), Associated Professor
yevgen.maslyanenko@odaba.edu.ua, ORCHID: 0009-0009-2982-375X
Korshak O.M., PhD (Tech), Associated Professor
korshak@odaba.edu.ua, ORCHID: 0000-0001-7346-252X
Odesa State Academy of Civil Engineering and Architecture

Abstract. Compared to traditional building materials and techniques, the use of prefabricated modular structures has the potential to solve the problems of environmental impacts such as energy consumption and the associated carbon dioxide emissions. The use of materials with a high potential for recycling and reuse, such as steel in the form of rolled or cold formed profiles, is fully in line with the principles of the circular economy - a shift from a linear to a circular material use.

Unlike rolled profiles with open and closed cross-sections made of structural steels, which use intumescent paints for fire protection, cold-formed steel profiles, due to their relatively small thickness, require the use of fireproof coatings of greater thickness (10-15 mm) based on gypsum or perlite. For galvanized profiles, the only fire protection method available is cladding using various types of fireboards.

The investigation of steel volumetric modules design economic factors influenced by different methods of fire protection were conducted at the Department of Metal, Wooden and Plastic Structures. Further investigation of economical design related factors of fire resistance of cold formed structures of volumetric modular construction intended to fill the gap.

The research is focused on the performance of cold formed steel bearing structures, as well as fire resistance of cold formed steel profiles and fire protection methods**.**

Keywords: cold formed steel, 3D-volumetric modules, fire resistance, steel buildings.

Introduction. Modern trends and directions of development of the global industry in general and construction in particular should take into account the solution of immediate practical problems of several global challenges.

The construction industry is currently responsible for a significant share of energy consumption and the associated carbon dioxide emissions. The “carbon footprint” of construction products consists of the extraction and processing of fossil fuels, manufacturing of materials, transportation, operation of machinery and equipment, construction and operation of buildings and structures, etc. In addition, construction production is responsible for the consumption of almost half of all extracted raw materials [1].

However, the environmental impact of construction production does not end with the life cycle of a building or structure. Both construction and demolition of obsolete and outdated facilities increase the amount of industrial waste that needs to be recycled or disposed of. To this list should be added facilities damaged by natural disasters that have become more frequent as a result of global warming and facilities damaged as a result of terrorist acts and hostilities related to armed aggression by the Russian Federation.

Compared to traditional building materials and techniques, the use of prefabricated modular structures has the potential to solve the above problems. "Shifting the industry dynamic from projects to products" [2] through factory production allows to reduce the quality of construction products and, accordingly, the need for materials, the amount of waste and the amount of energy consumed. The use of materials with a high potential for recycling and reuse, such as steel in the form of rolled or cold formed profiles, is fully in line with the principles of the circular economy - a shift from a linear to a circular material use.

Despite the fact that definitions of circular economy are vary from framework to framework, most of them originated to “ISO/DIS 59004 Circular Economy – Terminology, Principles and Guidance for Implementation”. The standard specifies the term “circular economy” as an economic system that uses a systemic approach to maintain a circular flow of resources through recycling, maintaining or increasing their value, and which contributes to sustainable development. Commonly, principles of circular economy refer as “4R” – “reduce, reuse, recycle, recover” [3].

Ensuring the durability, maintenance and safe operation of steel structures in general and modular structures in particular depends, not least, on the fire resistance of structures, which requires appropriate fire protection measures to ensure that the regulatory parameters are met.

Literature review. The research is focused on the performance of cold formed steel bearing structures, as well as fire resistance of cold formed steel profiles and fire protection methods. To analyze the relationships between key concepts in the literature related to cold form steel, fire resistance, and volumetric modular construction, VOSviewer 1.6.20 [4] software has been employed for creating network maps from scientific publications, providing visualization of terms interconnection and clustering based on co-occurrence analysis of keywords within the titles, abstracts, and texts of the articles.

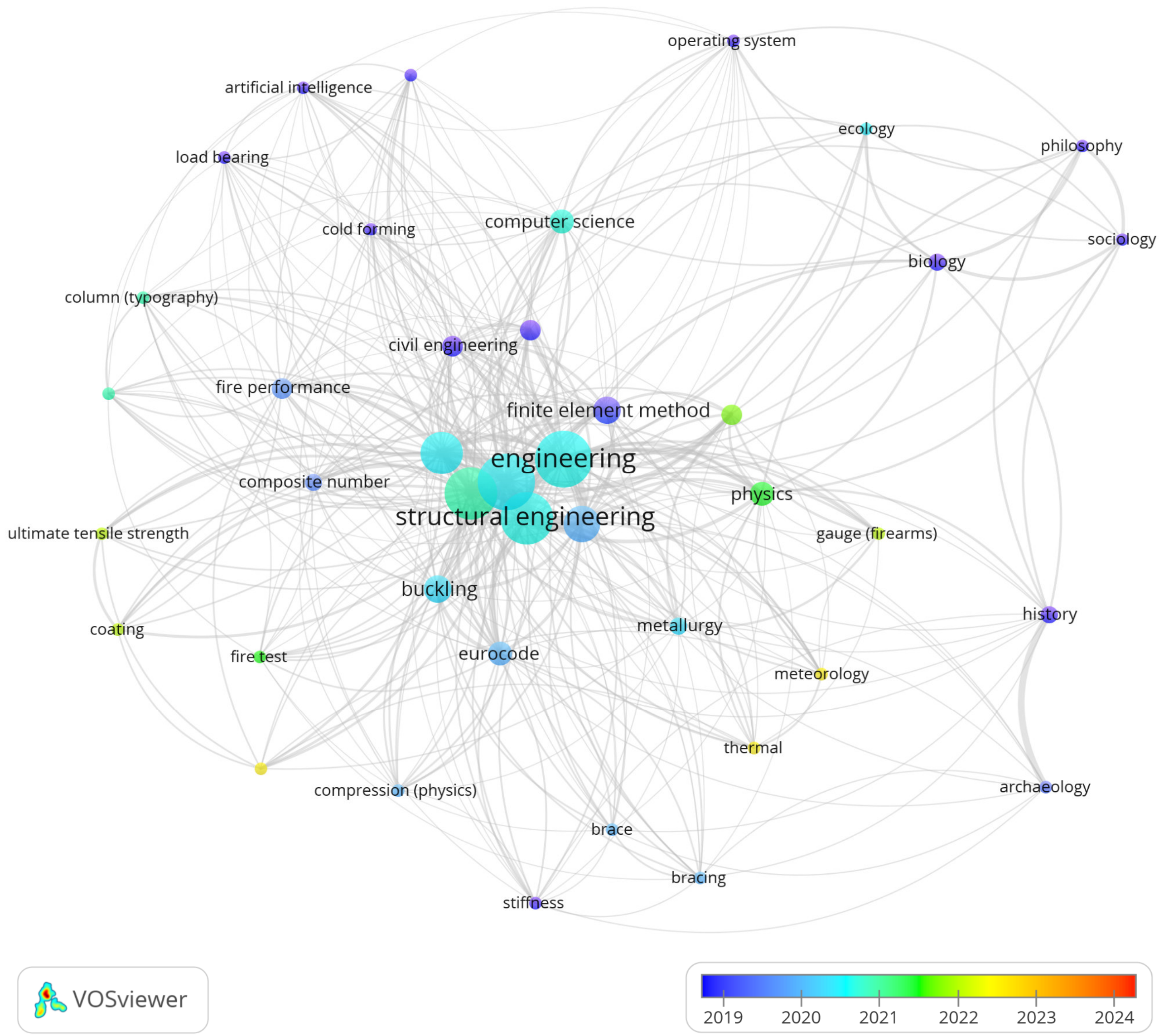

Fig. 1. Keyword mapping with VOSviewer 1.6.20

Fig. 1 presents the keyword map generated by VOSviewer 1.6.20. The nodes ("clusters") in the map represent the frequency of using keywords and their combinations. The connections between clusters indicate co-occurrence related to the same topics. The size of each cluster reflects the number of references to the particular keyword, and the density of the lines represents the strength of relationships between topics.

Besides the two major nodes in the analysis ("engineering" and "structural engineering") the most distinguished are "buckling", "finite element method", "computer science", "eurocode", and "fire performance", highlighting the significance of these topics in recent researches. The time scale shows predictable tendency to shift related to researches social topics toward "ecology".

The researches of cold-formed steel structures largely divided on two main groups: one group concentrated on the joints rigidity problems; other – investigated lateral stability and performance of stud wall systems.

Relatively small number of researches studied stud wall bearing capacity and their behavior under vertical load [5] or the influence of multi-hazard interactions, such us the fire pre-damage effects on the lateral load resistance of the strap-braced walls [6].

Among others, need to mention full-scale fire tests that investigated and characterized the collapse behavior of a single storey cold-formed steel (CFS) building [7] and related modelling of temperature effects using finite element method. The FE model developed in this study, simulated the performance of cold-formed steel cantilever wall/truss system at elevated temperatures. The FEA results demonstrated acceptable correlation with the full-scale fire test results, in terms of failure behavior, angle displacement and collapse temperature. It also proved that plaster board had significantly improved the thermal and structural performance of cold-formed steel stud wall panels.

Analyzing the mentioned above, it is safe to say that energy-saving and cost-effective solutions should be incorporated at the design stage, choosing those that are most effective in the long run. When choosing design solutions, it is necessary not only to ensure compliance with existing regulations and regulatory guidelines, but with frameworks that outline the prospects and directions of development of modern society.

Review Aims and Scope. Unlike rolled profiles with open and closed cross-sections made of structural steels, which use intumescent paints for fire protection, cold-formed steel profiles, due to their relatively small thickness, require the use of fireproof coatings of greater thickness (10-15 mm) based on gypsum or perlite [8]. For galvanized profiles, the only fire protection method available is cladding using various types of fireboards.

The investigation of steel volumetric modules design economic factors influenced by different methods of fire protection were conducted at the Department of Metal, Wooden and Plastic Structures [9]. Further investigation of economical design related factors of fire resistance of cold formed structures of volumetric modular construction intended to fill the gap.

Research Methodology. Similar to the previous research [8] the modules of overall size 3825×7650×3360 mm were designed by 3D modelling software Autodesk Advance Steel with a frame made of cold formed profiles ("Pruszynski") - stud walls with the plasterboard on both sides. Based on recommendation [8], alternative design developed with back-to-back (BB) composite profiles. For comparison purpose design with a frame made of rolled profiles (IPE I-beam and RHS profiles with light-weight decking) [9] have been included.

Research results. The results of the comparison of structural design solutions in factors of the dead weight of steel structures, the construction weight of the structural elements of the module and the cost, including fire protection of steel structures by applying intumescent paint to meet requirements of fire resistance class R30, fire protective coating and fire rated plaster boards to meet requirements of fire resistance class REI30, are shown in the following diagrams (the most effective of the solutions for each comparison category stated as 100%).

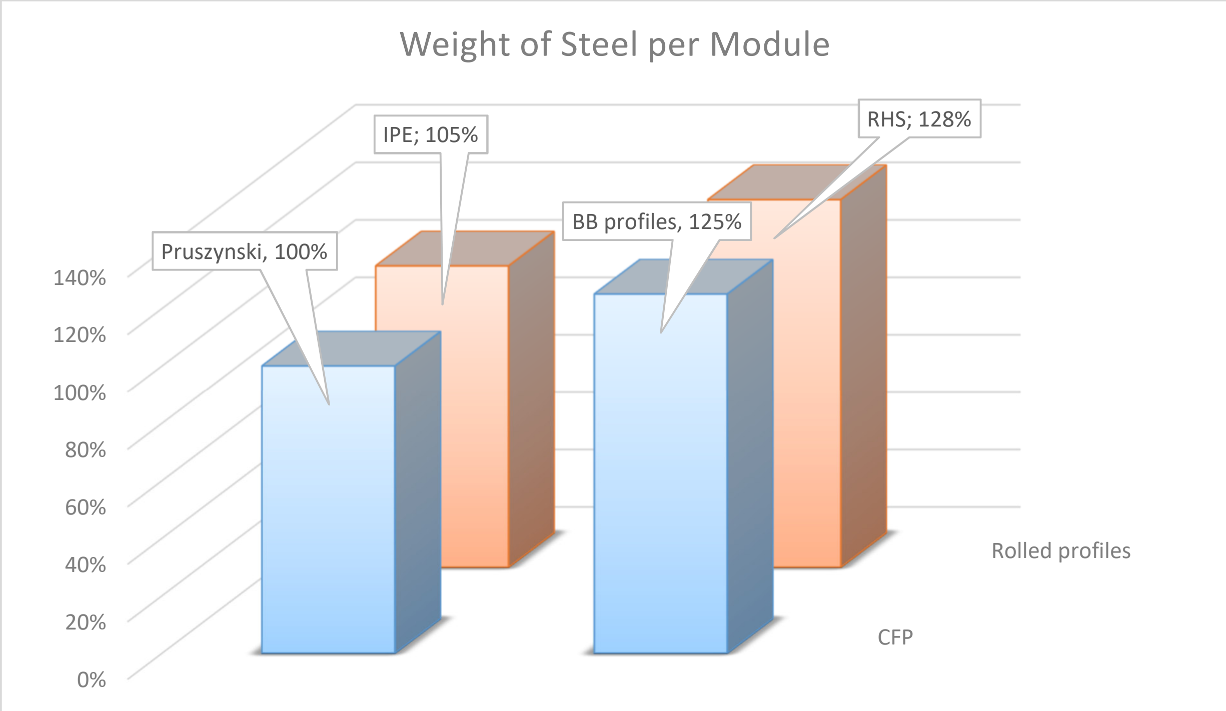

Fig. 2. Steel consumption per module ratio

As shown (Fig. 3), IPE rolled profiles frame is the best for reducing shipping weight of the modules (option with regular joists and composite deck)

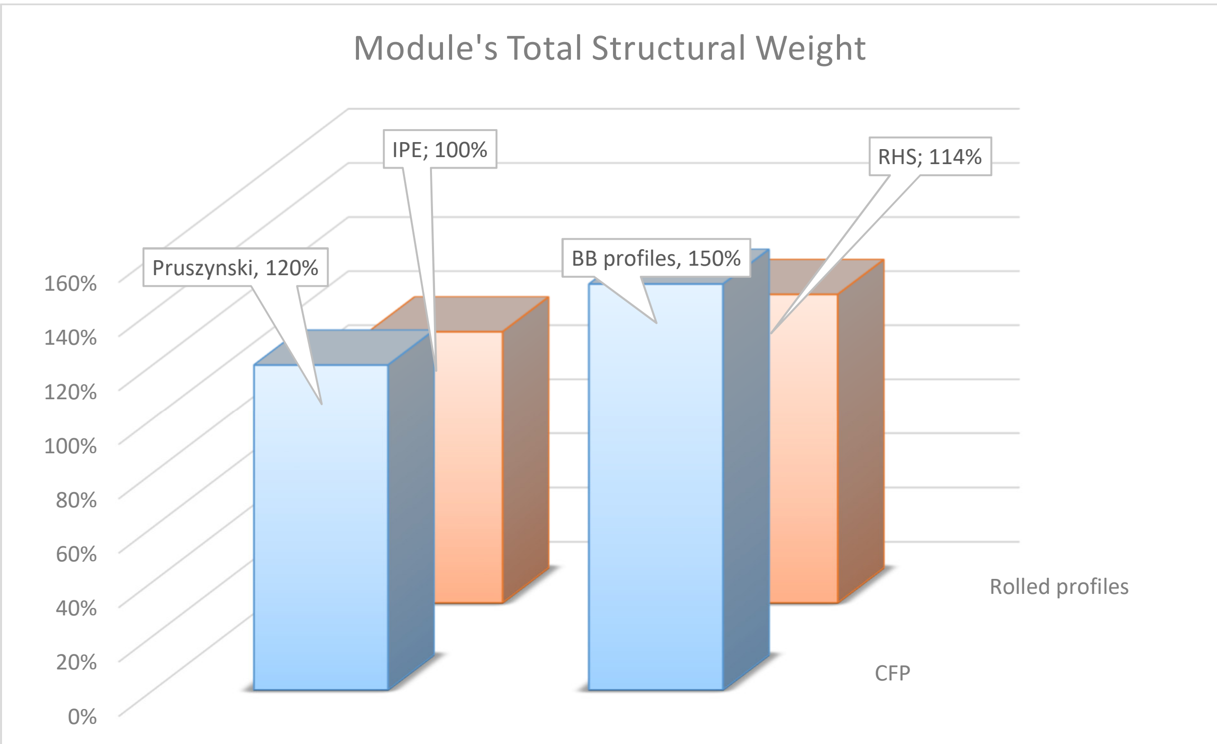

Fig. 3. Gross weight of the module structures comparison

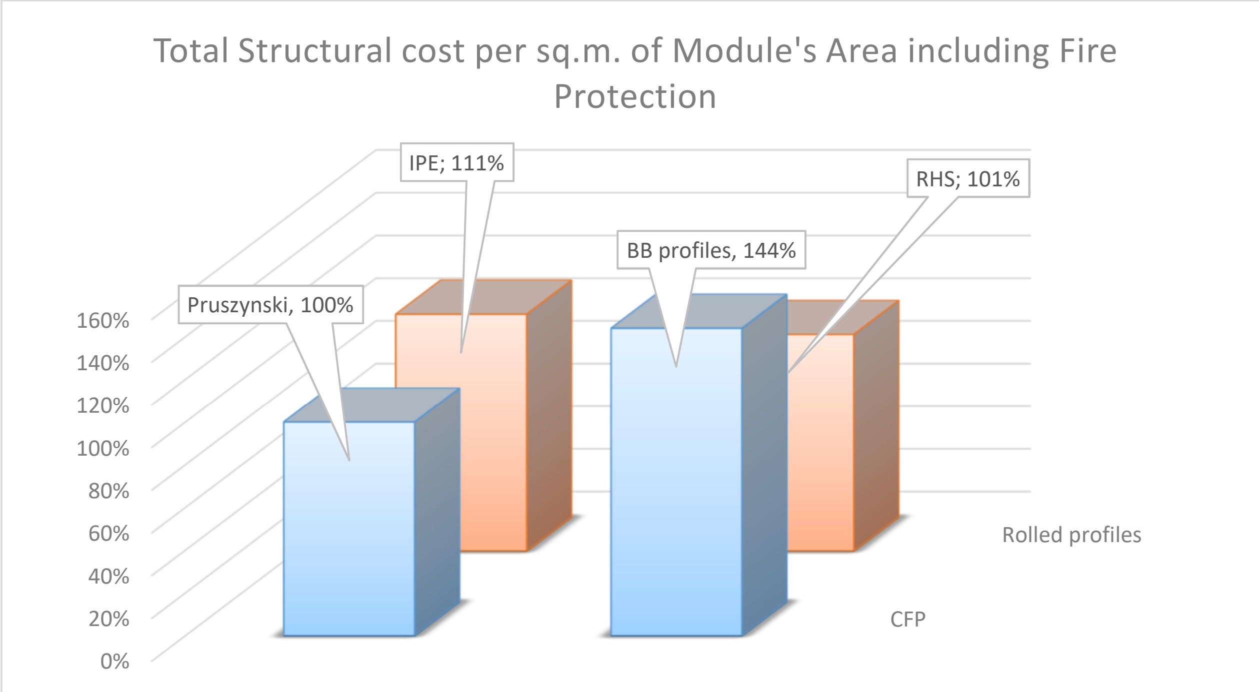

Fig. 4. Structural cost per sq.m. including Fire Protection (R30 for IPE and RHS, REI30 for CFS & plaster board assemblies)

Comparison of structural (net) cost of steel fabrication, plasterboard assemblies along with fire protection material demonstrates that modules cold-formed profile frames is the most effective design solution in terms of economic factors and workability (Fig. 4).

Conclusions.

1. The module frame elements in the form cold-formed profiles with plasterboards assemblies are more economically effective in terms of steel consumption per sq.m. of total area, however, the module frames made of RHS elements demonstrated almost similar efficiency with application of the intumescent paint (for fire resistance class R30 and more).

2. Thick fire protective coating (10-15 mm) is the least effective of the reviewed methods of fire resistance improvement of cold formed profiles.

References

[1] Gamage, I.; Senaratne, S.; Perera, S.; Jin, X. Implementing Circular Economy throughout the Construction Project Life Cycle: A Review on Potential Practices and Relationships. Buildings 2024, 14, 653. https://doi.org/10.3390/buildings14030653

[2] Masood, Rehan & Roy, Krishanu & Gonzalez, Vicente & Lim, James. (2024). Ameliorating Supply Chains of Prefabricated Housebuilding: An Integrated Performance Framework. Journal of Construction Engineering and Management. 150. 10.1061/JCEMD4.COENG-14404.

[3] Ottosen, L.M.. (2024). Innovations in building and bridge engineering associated with circular economy. 10.1201/9781003483755-8.

[4] VOSviewer1.6.20 – Visualizing Scientific Landscapes. Available online: https://www.vosviewer.com/

[5] Lawson, Robert & Way, Andrew & Heywood, Martin & Lim, James & Johnston, Ross & Roy, Krishanu. (2019). Stability of light steel walls in compression with plasterboards on one or both sides. Proceedings of the Institution of Civil Engineers - Structures and Buildings. 173. 394-412. 10.1680/jstbu.18.00118.

[6] Hasanali, Maryam & Roy, Krishanu & Mojtabaei, Seyed Mohammad & Hajirasouliha, Iman & Clifton, George & Lim, James. (2022). A critical review of cold-formed steel seismic resistant

systems: Recent developments, challenges and future directions. Thin-Walled Structures. 180. 109953. 10.1016/j.tws.2022.109953.

[7] Roy, Krishanu & Lim, James & Lau, Hieng Ho & Ming, Yong & Clifton, George & Johnston, Ross & Wrzesien, Andrzej & Mei, Chee-Chiang. (2019). Collapse Behaviour of a Fire Engineering Designed Single-Storey Cold- Formed Steel Building in Severe Fires. Thin-Walled Structures. 10.1016/j.tws.2019.04.046.

[8] Sam, V.S.; Nammalvar, A.; Iswarary, A.; Andrushia, D.; Ananthi, G.B.G.; Roy, K. Effect of Protective Coatings on Post-Fire Performance and Behavior of Mild Steel-Based Cold-Formed Steel Back-to-Back Channel Columns with Bolted Connections. Fire 2025, 8, 107. https://doi.org/10.3390/fire8030107

[9] Maslyanenko Y.V., Korshak O.M. Odesa State Academy of Civil Engineering and Architecture. Comparison of General Technical Parameters, Workability and Fire Protection of Rolled Profiles Vs. RHS Steel Frames of 3D Volumetric Modules. Modern Structures of Metal and Wood. Vol. 28, June 2024, pp. 24-28. ISSN: 2707-3068. http://doi:10.31650/2707-3068-2024-28-24-29

ВОГНЕСТІЙКІСТЬ КАРКАСІВ 3D-ОБ'ЄМНИХ МОДУЛІВ ІЗ СТАЛЕВИХ ХОЛОДНОФОРМОВАНИХ ПРОФІЛІВ У ПОРІВНЯННІ З ПРОКАТНИМИ СТАЛЕВИМИ ПРОФІЛЯМИ

Масляненко Є.В., к.т.н, доцент
yevgen.maslyanenko@odaba.edu.ua, ORCHID: 0009-0009-2982-375X
Коршак О.М., к.т.н, доцент
korshak@odaba.edu.ua, ORCHID: 0000-0001-7346-252X
Одеська державна академія будівництва та архітектури

Анотація. У порівнянні з традиційними будівельними матеріалами і технологіями, використання швидкомонтованих модульних конструкцій має потенціал для вирішення проблем впливу на навколишнє середовище, таких як споживання енергії та пов'язані з цим викиди вуглекислого газу. Використання матеріалів з високим потенціалом переробки та повторного використання, таких як сталь у вигляді прокату або холодноформованих профілів, повністю відповідає принципам циркулярної економіки - переходу від лінійного до кругового використання матеріалів.

На відміну від прокатних профілів відкритого і закритого перерізу з конструкційних сталей, для вогнезахисту яких використовуються інтумесцентні фарби, холодногнуті сталеві профілі через свою відносно невелику товщину вимагають застосування вогнезахисних покриттів більшої товщини (10-15 мм) на основі гіпсу або перліту. Для оцинкованих профілів єдиним доступним методом вогнезахисту є облицювання різними типами протипожежних плит.

Дослідження зосереджене на експлуатаційних характеристиках несучих сталевих холодногнутих конструкцій, а також на вогнестійкості холодногнутих сталевих профілів і методах вогнезахисту.

Елементи модульної рами у вигляді холодногнутих профілів з гіпсокартонними збірками є більш економічно ефективними з точки зору споживання сталі на квадратний метр загальної площі, проте модульні рами, виготовлені з елементів RHS, продемонстрували майже таку ж ефективність при застосуванні вогнезахисної фарби (для класу вогнестійкості R30 і вище).

Товсте протипожежне покриття (10-15 мм) є найменш ефективним з розглянутих методів підвищення вогнестійкості холодногнутих профілів.

Ключові слова: холодноформована сталь, 3D-об'ємні модулі, вогнестійкість, сталеві будівлі.