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Structural Solution of Roofing Applying Sheet-plates

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Abstract. *The demand for advanced building materials has grown due to new requirements for the thermal resistance of enclosing and load-bearing structures. This study explores energy-efficient and cost-effective solutions in industrial and construction sectors. The authors investigated how long-term loading affects the mechanical properties of particleboard. The analysis of extended static testing provided important insights into the material's durability. Additionally, the research contributes not only to increasing the production of heat-insulating materials but also to addressing the issue of wood waste utilization. The design of materials and structures using wood waste takes into account the physical and mechanical properties of the wood filler and the overall wood structure. The study indentifies key benefits of modern technologies in the manufacturing and construction of buildings using composite wood – based materials. Based on their findings, the authors suggest using cement-bonded particleboards for roofing structures with sheet the roof slope.*

Keywords: *mechanical properties, wood structure, issue, sheet, roof slope, building materials, industrial sector.*

Introduction

The purpose of this study is to develop a roof structure applying cement-bonded particle boards (CBPB), conduct a comprehensive analysis of its stress-strain state and establish an approximate method for calculating its strength and deformability on an elastic foundation. CBPB, which serve both load-bearing and enclosing functions are used in the roofing of low-rise and manor houses. A numerical and experimental investigation was conducted to analyze the stress-strain behavior of the roof structure, treating CBPB as a transversely isotropic plate supported by elastically deformable wooden battens. The study included calculations for both strength and deformability (first and second limit states), considering the combined performance of CBPB and wooden battens under short-term and long-term loads. Based on the numerical findings, recommendations were developed for an approximate method of calculating the strength and deformability of CBPB in roof structures. The practical significance of the work lies in the design proposals and experimental results, which provide guidelines for the design and simplified of roof structures incorporating CBPB [1].

Research methods

The approximate content of each component in the production mixture is given as a percentage of the total mass of Figure 1.

To produce 1m^3 of CBPB the following materials are required: 280 kg of absolutely dry wood chips, 770 kg of Portland cement M500, 45 kg of chemical additives and 500 l. of water.

CBPB combines the beneficial properties of both wood and concrete, outperforming plywood, chipboards and absorption and swelling rates than chipboards and demonstrates high resistance to environmental factors. The swelling of CBPB boards is minimal 0.5% compared to chipboard and their linear expansion due to moisture variation is only 0.02% for every +1% change in humidity.

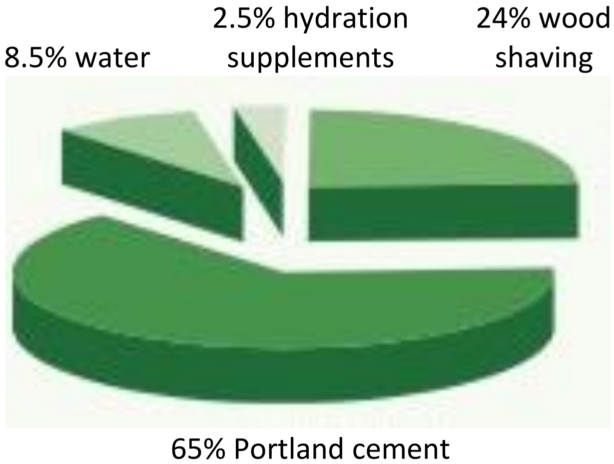

Figure 1 – Percentage composition of the components in the CBPB production mixture

CBPBs exhibit significant fire resistance (classified as G1). For instance, panel houses with a wood frame and single-layer CBPB cladding fall under fire resistance category IV. When an additional 12 mm layer of gypsum board is added, along with structural enhancements, buildings can achieve fire resistance category II with a REI 60 rating, making it possible to construct panel houses with wooden frames up to three stories high [2].

As a cladding material, CBPB belong to the category of flame-retardant and fire-resistant materials. According to the standard, CBPB is classified as G1 (low flammability) and has a low smoke emission rating. In the event of a fire, CBPB does not release toxic gases or vapors.

The industry produces two grades of CBPB with distinct physical and mechanical properties: CBPB №1, CBPB №2. Table 1 presents the standardized and additional performance indicators [3].

According to both domestic and international researchers, CBPB exhibits excellent adhesion properties and strong resistance to screw and nail pullout from both the surface and edges. These boards can be processed using conventional tools; however, cutting components must be non-toxic. Additionally, their surface can be refined. CBPB surface can be puttied, painted, wallpapered, tiled with ceramics or plastered [4].

To determine the elastic properties, CB specimen with a thickness of 12 mm and dimensions of 75×250 mm were tested. The supports and the testing machine's knife had rounded 15 mm each with a support center spacing of 200 mm.

During testing, the samples were positioned on the supports so that the applied force was perpendicular to the plate and centered. The test was conducted applying an R-5 testing machine, with a loading speed of 0.01 mm/sec. Samples were subjected to uniform loading and unloading, ranging from 5% to 25% of the failure load with an accuracy to 1-2% and the cycle was repeated. The duration of each loading cycle (from 5-25%) was maintained at 90 sec.

From the last three tested samples, absolute deformation values were calculated as the arithmetic mean between the upper and lower load limits. The modulus of elasticity was determined using the following equations

$$E_n = \frac{Pl^3}{4bh^3 f}, \quad (1)$$

where P is the applied load, equal to the difference between the upper and lower load limits;

- f is the deflection, measured as the difference in displacement at the upper and lower loading limits;

- h is the thickness of the chip-boards.

The test results are illustrated in Table 1. For CB samples with a thickness of 14 mm, the modulus of elasticity was determined by interpolating the values obtained for plates with a thickness of 12 mm and 14 mm [5]. Mechanical and physical characteristics of CB under prolonged loading conditions were obtained by applying correction factors to short-term loads values:

- long-term resistance mDA = 0.49;
- long-term deformability mDA = 0.52.

The elastic characteristics of the CB apply in further calculations are summarized in Tables 2-3.

For each element of the thin-walled plate (chipboard (CB) elements), the calculation results provide moments per unit length and membrane stresses. To evaluate the influence of various task parameters on the accuracy of the results, preliminary calculations were conducted before the main calculations. These preliminary computations helped determined the optimal characteristics of the calculation scheme, balancing computational efficiency (machine time) and calculation accuracy in Table 4.

To optimize calculations and reduce computational time, the geometric symmetry of the roof structure was considered. Initially, the design scheme was calculated for the entire roof, followed by a calculation for half of the roof [5]. The results were then compared to verify consistency between the full-roof model and the half-roof model.

The influence of grid density in the discretization of the continuum system apply rectangular elements was also analyzed. The contin-

Table 1 – Standardized and additional indicators

Indicators	Brand of slab	
	CBPB-1	CBPB-2
Density kg/m^3	1100-1400	
Moisture, %	9±3	
Thickness swelling in 24 h, %	2	
Bending strength, MPa, slabs, thickness 8-16 mm 18-24 mm	 12 10	 9 8
Tensile strength perpendicular to the plate, MPa	0.40	0.35
Plate roughness, mkm Unpolished slabs Polished	 320 80	 320 100
Bending modulus, MPa	3500	3000
Hardness, MPa	45-65	
Specific resistance to screw pullout from slabs, N/m	4-7	
Specific heat capacity, kJ/kg·°C	1.15	
Thermal conductivity, W/m·°C	0.25	
Bio-resistance class	4	
Bending strength decrease, % after 20 cycles of temperature and humidity effects	30	
Thickness swelling, %	5	
Flammability	Flame retardant	

Table 2 – Elastic characteristics

Indicators	Plate thickness, mm		
	10	12	14
The modulus of elasticity of chipboard when bending perpendicular to the plane, E, MPa a) short-term b) long-term	 3320 1400	 4110 1710	 5010 2084
Shear modulus, MPa a) short-term b) long-term	 2850 1197	 3013 1253	 3170 1319
The Poisson's ratio	0.17	0.17	0.17

uum system, consisting of CB elements, then into 64 elements and finally into 144 elements. A comparison of the results with varying grid densities (CB and wooden crates with straight elements) demonstrated that satisfactory convergence was achieved when CB sheets were divided into square elements measuring 15×15 cm, as shown in Figure 2. For easier data processing and analysis a finer grid of 10×10 cm^2 was ultimately apply.

Result and Discussion

For the roof structure roof structure calculations, the IV snow region was considered with a snow load of Rh=1.5 kN/m^2 and s roof slope of 14°. The calculated evenly distributed snow load on the roof is 1.649 kN/m^2. The rafter spacing, typical for low-rise and manor house roofs, was taken as 800 mm, 1000 mm, 1200 mm, 1500 mm, 1800 mm. Loads from adjacent CBPB along with operational, self-weight

Table 3 – Data for calculating crates

Indicators	Cross section, mm			
	40×40	**50×50**	**60×60**	**70×70**
Cross-sectional area F, sm	16	25	36	49
Moment of inertia per torsion, J_{tor}, sm^4	85.3	208.3	432	800.3
Moment of inertia per bend, J_{bend}, sm^4	21.3	52.1	108	200
Modulus of elasticity E, MPa a) long-term b) short-term	 10000 12300	 10000 12300	 10000 12300	 10000 12300
Density, kg/m^3	500	500	500	500
The Poisson's ratio μ xy μ yx	 0.5 0.02	 0.5 0.02	 0.5 0.02	 0.5 0.02

Table 4 – Coefficients of the element stiffness matrix

Indicators	Thickness of the CB, mm		
	10	**12**	**14**
Material density P, kg/m^3	1400	1400	1400
Coefficients of the element stiffness matrix: - during prolonged exposure to loads: $C_{xx} = C_{yy}$ $C_{xy} = C_{yx}$ $C_{xs} = C_{ys}$ - with short-term effects of loads: $C_{xx} = C_{yy}$ $C_{xy} = C_{yx}$ $C_{xs} = C_{ys}$	 1442 2451 0 - - -	 1760.8 2994 0 4232.8 719.6 0	 2146.4 364.9 0 - - -

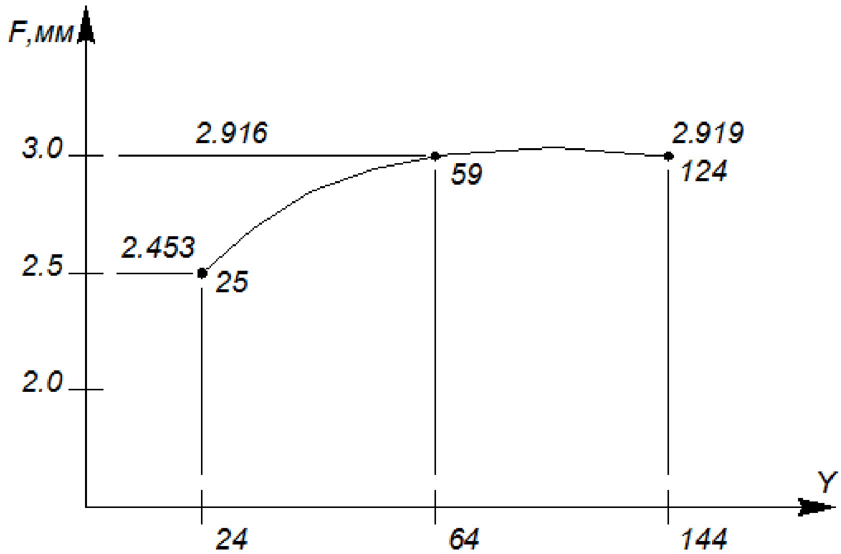

Figure 2 – Graph of convergence of calculation results

and temporary loads are transferred through the crate nodes obtained from discretization.

Computer simulations of the roof structure based on CBPB plate bending theory (Figure 3) indicate that maximum bending moments occur in the thin plate elements at section III-III, specification above the middle crate at its support points on the rafters.

Maximum displacements in the CBPB sheets occur at 0.43 from the outermost crate supports, which corresponds to the midpoint between adjacent crates (Figure 3). This behavior is due to the combined action of CBPB sheets and wooden crates, as the maximum movements in the two-span crate system also occur at 0.43 from the extreme supports.

When comparing displacement values based on plate bending theory versus beam bending theory, the displacements in CBPB are found to be lower in the plate bending model. On average, displacement values are 29.8% lower for a rafter pitch of 800 mm, decreasing to 18.5% for a pitch of 1500 mm, as demonstrated in Table 2.

Additionally, calculations applying the finite element method illustrated that the maximum moments and displacements in wooden crates, when analyzed together with CBPB, deviate only slightly (0.5-1%) from their expected values.

Further analysis of maximum moments and displacements was performed for CBPB sheet placement perpendicular to the roof slope. Figure 3 demonstrates the sealing of joint particle board sheets.

A long-term study of CBPB roofs with sheets laid along the roof slope in an indoor environment demonstrated a gradual increase in plate

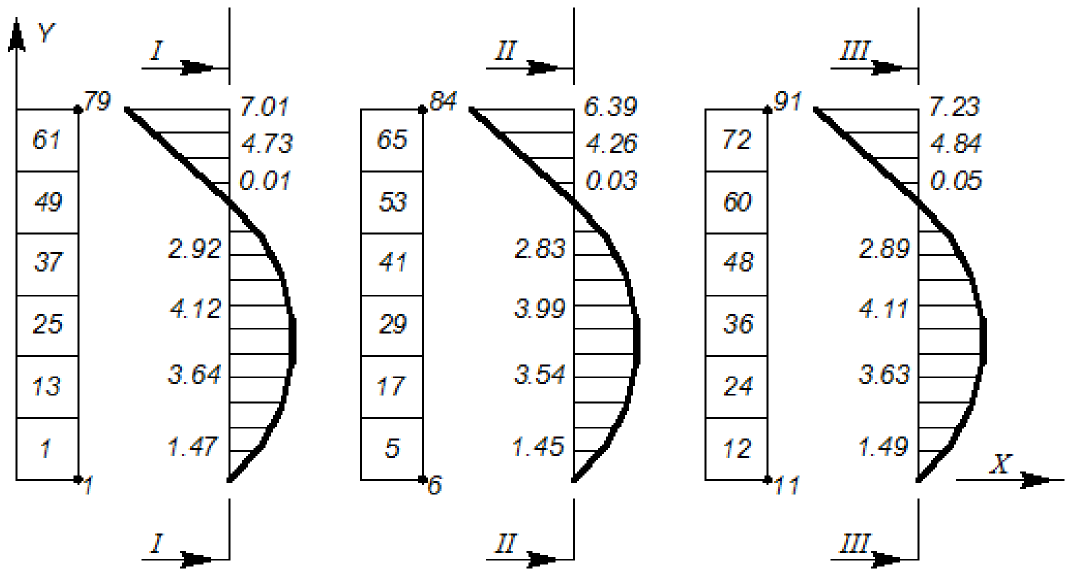

Figure 3 – Plot of the moments when laying out the CB across the roof slope

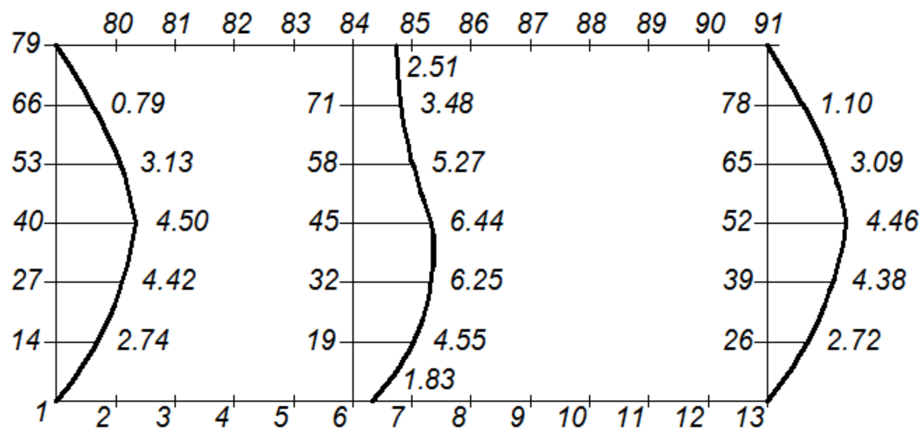

Figure 4 – The value of deflections of the CB when laying out the roof brackets

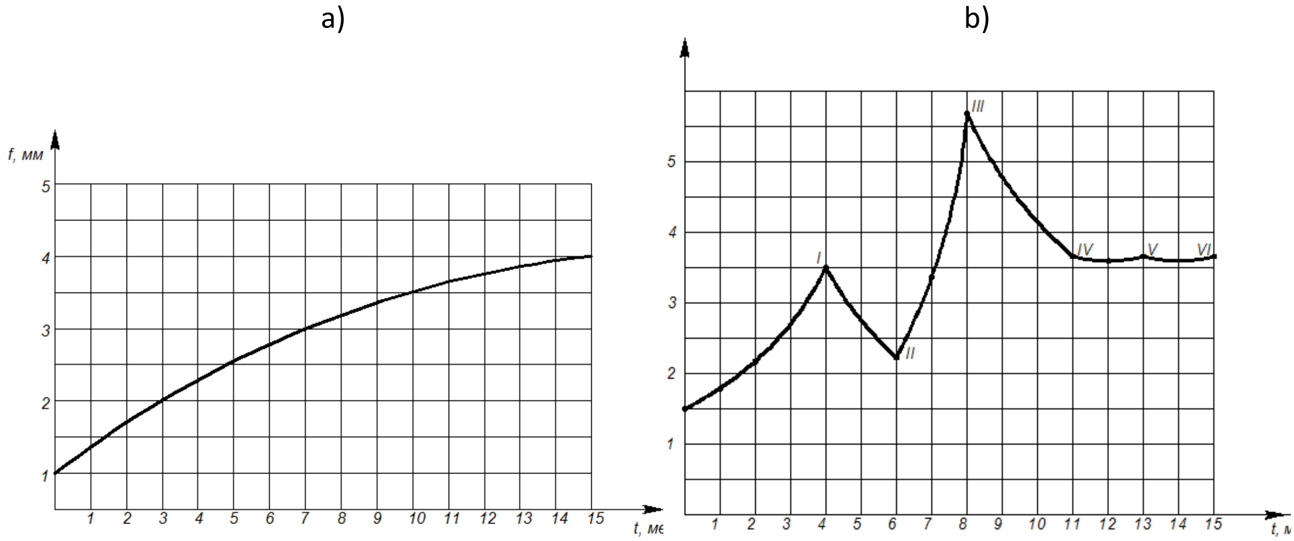

Figure 5 – Long-term study of roof deformability
a) in a room with a stable temperature (15-20°C) for 15 months
b) in atmospheric conditions for 15 months

deformations over 15 months. This behavior is attributed to creep in the CBPB, leading to a gradual deformation increase that eventually stabilized over time.

In contrast, long-term observations of CBPB roofs with sheets laid across the roof slope recorded a gradual deformation increase over four months. The strain value at point 1 was first measured three months after the start of testing.

Conclusion

For roofing solutions in manor and low-rise buildings, CBPB-based roofing structures are recommended with sheets laid either across or along the roof slope. The key design approach involves applying large-format CBPB sheets, which serve both load-bearing and enclosing functions. This significantly reduces material consumption and construction labor costs.

For practical implementation during the variant design stage, the author's approximate method for calculating strength and deformability of CBPB roofing sheets is recommended. This method, developed based on research findings, utilizes coefficient that vary depending on sheet layout, rafter spacing and the pitch and cross-section of wooden battens.

REFERENCES

1. Omarov Zh., Tleulenova G., Makashev K. Modern energy efficient and industrial technologies of using composite materials and structures on the basis of wood waste. Mechanics and Technologies Scientific Journal, Dulaty University Vol. 2, 2025.
2. Omarov, Z., Zhukenova, G., Bulyga, L., Beisembaev M. Prospects for the use of sandwich panels in the construction industry of Kazakhstan. E3S Web of Conferences 263, 01020, 2021. FORM-2021. https://doi.org/10.1051/e3sconf/202126301020
3. Omarov, Zh.M., Zhukenova, G.A., Kuderin M.K., Bulyga, L.L. Beisembaev M.K. Method for Calcula-ting the Strength and Deformability of Roof Sheets Made of Cement Bonded Particle Board (scopus) 2021. Cite as: AIP Conference Proceedings 2559, 050004, 2022. https://doi.org/10.1063/5.0100336 Published Online: 16 August 2022
4. Junfeng Hou, Yongming Jin, Wenbo Che, YoumingYu. Value-added utilization of wood processing residues into cement-bonded particleboards with admirable integrated performance. Construction and Building Materials. 2022. https://doi.org/10.1016/j.conbuildmat.2022.128144

5. Liang Chen, Lei Wang, Daniel C.W.Tsang, Viktor Mechtcherine, Chi Sun Poon. 2018. Efficacy of green alternatives and carbon dioxide curing in reactive magnesia cement-bonded particleboards, (Journal of Cleaner Production), Vol. 258, 2020. https://doi.org/10.1016/j.jclepro.2020.120997

Тақта-тақтайшаларының қолданылуымен шатырдың құрылымдық шешімі

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Аңдатпа. *Жетілдірілген құрылыс материалдарына сұраныс қоршау және жүк көтергіш құрылымдардың жылу кедергісіне қойылатын жаңа талаптарға байланыс өсті. Бұл зерттеу өнеркәсіптік және құрылыс секторларындағы энергияны үнемдейтін және үнемді шешімдерді зерттейді. Авторлар ұзақ мерзімді жүктеменің бөлшектер тақтасының механикалық қасиеттеріне қаншалықты әсер ететінін зерттеді. Кеңейтілген статикалық тестілеуді талдау материалдың беріктігі туралы маңызды түсінік берді. Сонымен қатар, зерттеу жылу оқшаулағыш материалдардың өндірісін ұлғайтуға ғана емес, сонымен қатар ағаш қалдықтарын кәдеге жарату мәселесін шешуге де ықпал етеді. Ағаш қалдықтарын пайдаланатын материалдар мен конструкциялардың конструкциясы ағаш толтырғыштың физикалық-механикалық қасиеттерін және жалпы ағаш құрылымын ескереді. Зерттеу композициялық ағаш негізіндегі материалдарды пайдалана отырып, ғимараттарды өндіру мен салудағы заманауи технологиялардың негізгі артықшылықтарын анықтайды. Өз нәтижелеріне сүйене отырып, авторлар шатырдың еңісі бар шатыр құрылымдары үшін цементпен байланысқан бөлшектер тақталарын пайдалануды ұсынады.*

Кілт сөздер: *механикалық қасиеттері, ағаш құрылымы, мәселе, парақ, шатырдың беткейі, құрылыс материалдары, өнеркәсіптік секторы.*

Конструктивное решение кровли с применением листов-плит

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Аннотация. *Спрос на современные строительные материалы вырос в связи с новыми требованиями к термостойкости ограждающих и несущих конструкций. В данном исследовании рассматриваются энергоэффективные и экономичные решения в промышленности и строительстве. Авторы исследовали, как длительная нагрузка влияет на механические свойства древесностружечных плит. Анализ результатов длительных статических испы-*

таний позволил получить важную информацию о долговечности материала. Кроме того, исследование способствует не только увеличению производства теплоизоляционных материалов, но и решению проблемы утилизации древесных отходов. При проектировании материалов и конструкций с использованием древесных отходов учитываются физические и механические свойства древесного наполнителя и общая структура древесины. В исследовании определены ключевые преимущества современных технологий в производстве и строительстве зданий с использованием композитных материалов на основе древесины. Основываясь на своих выводах, авторы предлагают использовать цементно-стружечные плиты для кровельных конструкций с листовым уклоном крыши.

Ключевые слова: *механические свойства, структура древесины, проблема, лист, скат крыши, строительные материалы, промышленный сектор.*

REFERENCES

1. Omarov Zh., Tleulenova G., Makashev K. Modern energy efficient and industrial technologies of using composite materials and structures on the basis of wood waste. Mechanics and Technologies Scientific Journal, Dulaty University Vol. 2, 2025.
2. Omarov, Z., Zhukenova, G., Bulyga, L., Beisembaev M. Prospects for the use of sandwich panels in the construction industry of Kazakhstan. E3S Web of Conferences 263, 01020, 2021. FORM-2021. https://doi.org/10.1051/e3sconf/202126301020
3. Omarov, Zh.M., Zhukenova, G.A., Kuderin M.K., Bulyga, L.L. Beisembaev M.K. Method for Calcula-ting the Strength and Deformability of Roof Sheets Made of Cement Bonded Particle Board (scopus) 2021. Cite as: AIP Conference Proceedings 2559, 050004, 2022. https://doi.org/10.1063/5.0100336 Published Online: 16 August 2022
4. Junfeng Hou, Yongming Jin, Wenbo Che, YoumingYu. Value-added utilization of wood processing residues into cement-bonded particleboards with admirable integrated performance. Construction and Building Materials. 2022. https://doi.org/10.1016/j.conbuildmat.2022.128144
5. Liang Chen, Lei Wang, Daniel C.W.Tsang, Viktor Mechtcherine, Chi Sun Poon. 2018. Efficacy of green alternatives and carbon dioxide curing in reactive magnesia cement-bonded particleboards, (Journal of Cleaner Production), Vol. 258, 2020. https://doi.org/10.1016/j.jclepro.2020.120997