Analysis of low requirement justification of the current standard for the strength of wood particle boards

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Abstract. Currently, wood particle boards made of crushed shavings are widely used in the production of cabinet furniture, despite their shortcomings. The volume of particle board production in Russia is constantly growing. The main disadvantages of the boards include their toxicity associated with the release of gas (formaldehyde) harmful to humans above the permissible level (PL = 0.01 mg/m³ of air), low strength properties (especially bending strength) and limited areas of application of the boards. If we trace the dynamics of the technical requirements for these properties of boards according to the standards, then the question arises - what is the reason for the decrease in the requirements for the strength of boards in bending and, in this regard, the limitation of the application areas of particle board? A regular decrease in the requirements in the newly introduced State Standards has been constantly occurring since 1977, but this is especially noticeable in the current 10632-2014 State Standard. This article focuses on the possible objective and subjective reasons for the low requirements of the current standard for the strength of wood particle board.

1. Introduction
Production of wood particle boards (WPB) in Russia and abroad is constantly growing [1-4]. This is mainly due to the fact that chipboards are classified as environmentally friendly materials that can replace natural wood and even surpass it in some characteristics. This material is made mainly of woodworking waste, which does not require additional logging activities, and contributes to the forest preservation. But it enables to prepare a practical and reliable material from low quality wood and appropriate waste, which serves as the basis for durable, strong products and structures. Due to the tightening of sanitary and hygienic requirements for the materials produced and the growing need for environmentally friendly products among consumers, chipboard manufacturers are introducing technologies for production of boards without the use of formaldehyde, which has toxic effect on the human body. However, with the introduction of new standards for boards, the requirements for physical and mechanical properties of boards are constantly decreasing. This applies especially to the ultimate strength in bending. The influence of modern technologies on the quality of particle board is partially considered in the article [5]. If we trace the dynamics of such a decrease, then if this indicator according to GOST (State Standard) 10632-77 [6] was, depending on the brand of the board, 14.71-24.51 MPa, then according to GOST 10632-89 [7] it was already 14.0-16.0 MPa, and according to GOST 10632-2007 [8] – 11.5-13.0 MPa, and according to the current GOST 10632-2014 [9] – 10.0-11.0 MPa. Table 1 shows data on the change in bending strength according to the above standards in % to the GOST 1977 indicator for P-2 plates of group A, as the most common plates. As follows from these data, since
1977 bending strength has decreased by 37.7% for brand R2 and by 43.4% for brand R1. Another strength indicator of boards (tensile strength perpendicular to the board) has decreased by 30.4% for R1 brand and slightly increased (by 1.4%) for R2 brand since 1977.

The purpose of this work is to analyze justification of low requirements of the current standard for the strength of wood particle board.

Table 1. Technical requirements for particle board in accordance with GOSTs (State Standards), from 1977 to the present.

| Indicator | GOST 10632-77 for brands and groups [6] | GOST 10632-89 for brands [7] | GOST 10632-2007 for brands [8] | GOST 10632-2014 for brands [9] |
|-----------|----------------------------------------|------------------------------|-------------------------------|-------------------------------|
|           | P-1 | P-2A | P-2B | P-3 | P-A | P-B | P-A | P-B | R1 | R2 |
| Tensile strength in static bending, MPa, for brands with a thickness, mm: | | | | | | | | | | |
| 15-19 | 100 | 100 | 87.8 | 138.9 | | | | | | |
| 13-19 | 100 | 100 | 79.3 | 138.9 | 73.6 | 65.2 | | | 56.6 | 62.3 |
| 14-20 | 138.9 | | | | | | | | |
| 13-20 | | | | | | | | | |

Tensile strength perpendicular to the board face, MPa, for boards with a thickness, mm:

| 15-19 | 100 | 100 | 85.5 | 113.6 | | | | | | |
| 13-19 | 100 | 87.0 | 87.0 | 101.4 | 69.6 | | | | |
| 14-20 | | | | | | | | | |
| 13-20 | | | | | | | | | |

It has been known for a long time, that bending strength of boards is influenced by a huge number of factors practically throughout the entire technological process. We will give only the main part of them: the type of raw material and its quality [10-13], which is characterized by the type of wood (mainly birch, aspen, alder, pine and some others are used) and diameter, the presence of heart rot, the method of supply of raw materials, debarked raw materials or unrooted ones; the season, the type of equipment used to obtain particles of the required geometric dimensions [14-16], especially for the outer layers of the plates (usually machines with a knife shaft of the DS-6 or DS-8 models are used); the quality of drying and sorting of wood particles (shavings); the type of binder used and the quality of mixing it with shavings; the quality of forming the chip-adhesive carpet; density of slabs; slab layering; type of equipment for hot pressing of plates; hot pressing of plates; method of cooling the plates and the place of installation in the workshop of cooling equipment; the presence of post-press curing of plates, etc. [17-20].

2. Methodology

So what has changed in the technology of board production, that since 1977 the requirements for bending strength have been regularly reduced? Or is it an objective decline or subjective? Yes, in terms of the objective decrease in this indicator, some changes have taken place. These include the following.

1. Use of low-toxic urea-formaldehyde resins (UFR) in technology. Starting from about 1970, low-toxic UFRs with a reduced content of free formaldehyde (molar ratio U:F = 1:1.5), which reduce the
toxicity of boards, are being introduced into the chipboard technology. This gives its positive effect when looking at the formaldehyde emission class [21]. Table 2 shows the main properties of resins used in particle board technology in different years. At this time, along with the widely used UFR brands M19-62 and UKS-A, the content of free formaldehyde in which it was 1.0 and 1.2%, respectively, resins with a reduced content of free formaldehyde (0.3 to 0.15%) are introduced. These resins include: KS-68M (0.3%); KF-MT (0.15-0.20%); KF-MT-15 (0.15%). Phenol-formaldehyde resin of the SFZh-3014 brand, containing only 0.1% of free formaldehyde, is tested as experimental one. This gives its positive results in reducing the emission of formaldehyde requirements from boards, which follows from the technical requirements of GOST (table 3). At the same time, it is known from the research results of a number of authors that the more free formaldehyde in formaldehyde resins, the more strength of their adhesion to wood or wood particles [22,23].

Table 2. The main properties of resins used in particle board technology in different years.

| Indicator                                      | M19-62 (1970-1989) | UKS-A (1970-1989) | KS-68M (1970-1989) | KF-MT (1990-2006) | KF-MT-15 (2006-till present) | KF-NFP (2006-till present) |
|------------------------------------------------|--------------------|-------------------|--------------------|-------------------|-----------------------------|-----------------------------|
| Solids content, %, not less                      | 60                 | 64                | 65                 | 64-66             | 64-68                       | 64-68                       |
| Viscosity according to VZ-4, s                   | 20-100             | 20-50             | 20-50              |                   |                             |                             |
| Concentration of hydrogen ions (pH)             | 7.2-8.5            | 7.5-9.0           | 6.5-8.0            | 7.0-8.2           | 7.5-8.5                     | 7.3-8.3                     |
| Gelation time at 100 °C                         | 40-80              | 50-80             | 35-55              | 60-70             | 50-70                       | 55-70                       |
| Free formaldehyde content, %, not more           | 1.0                | 1.2               | 0.3                | 0.15-0.20         | 0.15                        | 0.15                        |
| Ultimate shear strength over the glue layer of plywood after 24-hour soaking in water, MPa, not less | –                  | –                 | –                  | 1.6                | 1.6                         | 1.6                         |

Table 3. Technical requirements for formaldehyde emission standardsa.

| Indicator                                      | GOST 10632-89 [7] | GOST 10632-2007 [8] | GOST 10632-2014 [9] |
|------------------------------------------------|-------------------|---------------------|---------------------|
| Formaldehyde emission class                    | E1 (up to 10), E2 (over 10 to 30) mg /100 of abs. dry boards) Perforating test method | E1 (up to 8), E2 (over 8 to 30) mg/100 of abs. dry boards) Perforating test method | E0.5 (up to 4), E1 (over 4 to 8), E2 (over 8 to 20) mg/100 of abs. dry boards) perforating test method or E0.5 (up to 0.08), E1 (over 0.08 to 0.124), E2 (over 0124 to 0.5) Chamber test method |

aFormaldehyde emission class was not standardized according to GOST 10632-77

2. Untimely cooling of low-toxic resin boards unloaded from the hot press. According to the currently existing technology (as it was in ancient times), the boards unloaded from the hot press are immediately sent for cooling to a fan cooler, which is built in the main conveyor immediately after the hot press. In
it, the rotor, with 36 special stops welded to it, rotates in bearings resting on the struts. After separation from the pallets, the boards are fed one at a time to the stops of the rotor, which rotates one step as each board enters. The operation of board cooling prevents thermal destruction of a binder, which has a positive effect on the strength properties of the boards. However, our work showed that when using low-toxic resins in the technology of board (the experiments were carried out under industrial conditions when using a binder based on KF-MT-15 resin in the boards), the binder in the boards unloaded from the hot press is still not fully cured. It is a rubbery mass. Consequently, the conclusion suggests itself - either to increase the duration of pressing the boards, which entails a decrease in the production capacity of the workshop, or the boards unloaded from the press should not be cooled, but stacked, and, only then, cooled according to the developed modes on a special cooler. A patent for an invention was received for it (figure 1).

The device consists of a vertical tunnel 1, divided by partitions 2 into ventilation sections 3. The chain conveyor 4 is installed vertically and has a hydraulic drive for step-by-step movement of the chain. On each link of the chain, rollers are fixed to keep the racks 5 in a horizontal position, on which the boards 6 are laid. The device is equipped with a ventilation system, which includes supply fans 7 with regulating louvered grilles 8 and 9, exhaust fans 10 with louvered grilles 11. Air conditioners are mounted on the unit body 12. At the entrance to each ventilation section, a distribution grill 13 is installed, which evenly distributes air over the entire section. The ventilation sections are interconnected by recirculation boxes 14, which are located alternately on the outer and inner sides of each branch of the chain conveyor and are offset from one another by the size of the ventilation section. At the end of the tunnel there is a board loading opening 15 and an unloading opening 16. At the unloading opening there is mounted a laser radiation thermometer 17 of the CENTER 350 - INFRARED TERMOMETER LASER RADIATION brand to determine the surface temperature of the finished boards.

![Diagram](image)

**Figure 1.** Cooling device for low-emission particle boards.

The device works as follows. Particle board 6 through the loading opening 15 is fed into the tunnel to the racks 5. The vertical conveyor 4 with a hydraulic drive moves one step, while the cooled board is discharged from the unloading opening 16. Boards in the device are cooled according to a predetermined mode controlled by an automatic control system. To do this, the fan 7 through the louvers 8 and 9 is supplied to the chamber with the air of the workshop temperature. On the way to the boards, it is cooled.
by air conditioner 12 to a temperature of 10-15 °C. Cold air flows around the hot plates in the first ventilation section 3 from one side, and in the second section from the opposite side. Due to the counter flow of air and its distribution over the section of the distribution grids 13, uniform cooling of boards is achieved over the entire area. Exhaust air by fans 10 is discharged into the atmosphere through the grids 11. Beam device 17, installed at the inlet, records the surface temperature of the cooled boards. The measurement results are recorded and transferred to a PC, where the results are processed. If necessary, a signal is sent about a change in the cooling parameters (temperature and air speed). Cooling parameters are set depending on the surface temperature of the finished boards. Control over the process parameters and their regulation enables more efficient cooling, as well as reducing the time of this process. But in practice, at present, the boards are cooled immediately after they are unloaded from the hot press.

As a result, it turns out that the desire to reduce the toxicity of boards leads to a decrease in their strength. The question arises - how much can bending strength of the boards be reduced using FSC with 1% and 0.15% content of free formaldehyde in the particle board technology? Analysis of a number of works performed in the period from 1978 to 1982 using binders based on FSC brands M19-62 (1% free formaldehyde) and UKS-A (1.2% free formaldehyde) in particle board, as well as works performed in the period from 2006 to the present with the use of KFS brand KF-MT-15 (0.15% free formaldehyde), showed the following. With other conditions being the same for the manufacture of particle board, the ultimate bending strength of boards with resin containing 0.15% free formaldehyde is 10-15% lower (but this is not 37.7-43.4%! ) than this indicator for boards with M19 resins -62 (1% free formaldehyde) and UKS-A (1.2% free formaldehyde).

3. Results and discussion
In connection with the reduction in GOST 10632-2014 [9] of the requirements for the bending strength of boards, furniture makers complain that the boards arrive at the enterprise are loose, the edges crumble, and the fittings are attached to the edges of the boards with difficulty. This is where the subjective reasons for the decrease in the ultimate bending strength of board can be hidden. One of the possible reasons may be as follows. These are using cheaper wood raw materials and reducing the density of the boards. In the practice of chipboard production, such types of wood as birch, aspen, alder, pine, density of which is within 430-780 kg/m³ were mainly used. Moreover, pine, especially in recent years, is a more expensive and scarce species. But the chips obtained from this species are more durable. It is known that the higher the cohesive strength of the material used in the bonding technology, the more durable the final product can be obtained. In addition, pine chips are flatter and smoother. It enables a closer contact between the surfaces of the chips being glued together. Therefore, pine chips were used in the outer layers of the boards to obtain boards with higher flexural strength. Birch chips are inferior in strength to pine shavings, although the densities of these species do not particularly differ among themselves. Aspen and alder, the density of which is almost 2 times lower than the density of the above-mentioned two species, were usually used in the inner layer of the boards, which takes little load during board bending. Therefore, when making boards according to the current requirements for bending strength, enterprises have the option of a big maneuver to reduce the production cost. But using low density and low strength species in production leads to obtaining low density boards. All other things being equal, this entails a decrease in the ultimate bending strength of the boards and a decrease in the specific resistance to pulling out screws. And the reason for this may be low density of boards. Moreover, the dependences [5] are known that closely link the ultimate bending strength of boards with the density of the boards and binder content.

But after all, the density of the boards regulated by GOST 10632-2014 [9] is set almost the same as in the earlier standards (in GOST 10632-77 – 550-850 kg/m³, in GOST 10632-89 – 550-820 kg/m³, in GOST 10632-2007 – 550-820 kg/m³ and in GOST 10632-2014 – 550-820 kg/m³). Consequently, it can be assumed that manufacturers, taking advantage of the lowered requirements for the strength of boards, produce boards that meet the requirements for strength, but with a lower density. This is beneficial for them, since to obtain such boards, less consumption of raw materials and materials is required, the pressing pressure is reduced, and with it the hydraulic system of the press is taken care of, etc. All this,
ultimately, reduces the cost of production and increases the profit of the enterprise. After all, it has long been known that the ultimate bending strength, other things being equal, depends to a large extent on the density, especially of the outer boards. But besides this, the density of boards also significantly affects the resistivity of pulling out screws both from the face \( (g_{sc.pl.}) \) and from the edge of the plates \( (g_{sc.ed.}) \), which is important for fastening fittings. This parameter is largely related to the dependences on the board density \( (P) \) and the content of the binder \( (C_b) \) in them, and these dependences take the form:

\[
g_{sc.pl.} = 0.169P + 3.5 C_b - 63.7, \text{ N/mm},
\]

\[
g_{sc.ed.} = 0.153P + 3.75 C_b - 73.6, \text{ N/mm}.
\]

When \( P = 550 \text{ kg/m}^3 \) and \( C_b = 11\% \), then \( g_{sc.pl.} = 67.75 \text{ N/mm} \), and when \( P = 820 \text{ kg/m}^3 \) and equal \( C_b \), \( g_{sc.pl.} = 113.38 \text{ N/mm} \).

When \( P = 550 \text{ kg/m}^3 \) and equal \( C_b \), than \( g_{sc.ed.} = 49.05 \text{ N/mm} \), and when \( P = \text{kg/m}^3 C_b \), \( g_{sc.ed.} = 90.36 \text{ N/mm} \).

If we assume the adequacy of these formulas, then looking at the resistivity indicator for pulling out screws, we can conclude that this indicator is also much decreased according to GOST 10632-2014 (table 4).

**Table 4. Requirements of standards for boards for specific resistance to pulling out screws.**

| Indicator | GOST 10632-77 for brand P-2 and groups | GOST 10632-77 | GOST 10632-77 | GOST 10632-77 |
|-----------|----------------------------------------|---------------|---------------|---------------|
|           | A B P-A P-B P-A P-B R1 R2             |               |               |               |
| Specific resistance to pulling out screws, N/mm: | | | | | |
| -from the plate | 58.8-117.7 | 58.8-117.7 | 60 | 55 | 55-35 | 55-35 | 55-35 | 55-35 |
| -from the edge of the plate | 49-78.5 | 49-78.5 | 50 | 45 | 45-30 | 45-30 | 45-30 | 45-30 |

**Table 5. Fields of board application according to various standards.**

| Field of board application | GOST 10632-77 for brands [6] | GOST 10632-77 | GOST 10632-2007 | GOST 10632-2014 |
|----------------------------|-------------------------------|---------------|-----------------|-----------------|
| Furniture industry (furniture elements), construction (panels), radio, instrument making | + | | | |
| Furniture industry (furniture items), construction (panels, building structures, temporary structures), instrument cases, machines, containers (except food, containers, racks) | + | | | |
| Floors, roofs, wall panels, mezzanines, window sills, etc.; body and van parts, wagon partitions, etc. | + | | | |
| For the production of furniture, in construction (except for housing construction, the construction of buildings for children's, school and medical institutions), in mechanical engineering, radio equipment and in the production of packaging | + | | | |
| In industry and construction | + | | | |
| In conditions protected from moisture, for consumer goods, furniture and other types of products | + | | | |
As for the waterproof indicators of boards (swelling in thickness and water absorption), these indicators are generally excluded from the current GOST 10632-2014 [9]. This is understandable, since the range of board use is limited and such boards should only be used "in conditions protected from moisture, for consumer goods, furniture and other types of products", while the scope of use of boards according to the previous standards was much wider, up to the use in construction (table 5).

4. Conclusions
It is possible to increase the ultimate bending strength of boards and resistivity to pulling out screws by narrowing the limits of board density in the standard, focusing on the density of 750-770 kg/m$^3$. It is quite possible to produce boards with such a density on our presses of outdated models, albeit with a worn out hydraulic system of the presses due to its long-term operation. Increasing board density automatically entails the use of higher density wood species. The producers should be guided by the technological regulations for the production of three-layer particle board of low toxicity with resin consumption in the outer layers of 13-14% and in the inner layer - 9-11%. Cooling of plates immediately after their hot pressing should be excluded from practice and this section should be organized separately from the main conveyor using their own modes for cooling on a special device. The results obtained can be used in research on the development of optimal technological modes for the production of chipboard, to identify factors that have a negative impact on the physical and mechanical properties of boards in the process of their manufacture and to improve the quality of the materials obtained.

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