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Production of cement-bonded particleboards from poplar (*Populus euramericana* cv. „I 214“)

Proizvodnja drvno-cementnih ploča od topolovine (*Populus euramericana* cv. „I 214“)

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ABSTRACT • *The aim of our research was to develop a method for producing cement-bonded particleboards (CBPB) at the lowest possible cost. There are two possibilities for using poplar as raw material, and for using a new combination of chemicals as additives, the solution of calcium-chloride and calcium-formate instead of water glass. The present technology uses exclusively Scots pine (Pinus sylvestris) chips, which is getting increasingly expensive. The price of the new additive is lower, as well as the price of poplar compared to Scots pine. As a result of our research, the costs of CBPB production can be reduced. Physical and mechanical properties of the boards usually improved rather than deteriorated.*

Keywords: *cement-bonded particleboards, calcium-chloride, calcium-formate, poplar, scots pine, water glass*

SAŽETAK • *Cilj provedenih istraživanja bio je pronaći način proizvodnje drvno-cementnih ploča (CBPB) za koji će biti troškovi najmanji. Dvije mogućnosti za sniženje troškova jesu uporaba topolovine kao drvne sirovine za ploče te primjena nove kombinacije kemikalija – otopine kalcijeva klorida i kalcijeva formata umjesto vodenog stakla. U dosadašnjoj tehnologiji proizvodnje drvno-cementih ploča koristilo se isključivo iverje borovine (Pinus sylvestris), koje je svakim danom sve skuplje. Cijena topolova iverja u usporedbi s iverjem borovine niža je, kao i cijena predloženoga novog aditiva. Istraživanje je pokazalo da troškovi proizvodnje drvno-cementnih ploča na opisani način mogu biti smanjeni, a fizikalna i mehanička svojstva ploča ostala bi nepromijenjena ili bi se poboljšala.*

Ključne riječi: *drvno-cementne ploče, kalcijev klorid, kalcijev format, topolovina, borovina, vodeno staklo*

1 INTRODUCTION
1. UVOD

One of the most important aims of panel producers is to decrease the costs of raw materials and the costs of production itself. Of course this should be done by keeping the quality at a high level. Recently in Hungary cement-bonded particleboards (CBPB) have only been produced from Scots pine (*Pinus sylvestris*), whose procurement is increasingly difficult and hence the

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energetic use of forests and its price is also increasing. So it would be important to find an alternate wood species and develop possible modifications of production technology of new raw material.

These researches were based on domestic poplar clones (like sp. *Pannonia* or *euramericana*), because they are available in larger amount, and are suitable for plantations. On the other hand based on earlier researches these species can be suitable to produce CBPB because of their low inhibitor content (Takats, 2008). Also besides traditional water-glass (Na_2SiO_3) additive alternate chemicals were investigated: a solution of calcium-chloride and calcium-formate.

An earlier study (Illés, 2004) was made in this subject at the University of West Hungary. The author mixed poplar (I-214) with Scots pine in different ratios but used only water-glass as additive and made only single layer boards. The results were not clearly positive in case of bending strength.

Conventionally Scots pine chips are the raw material for CBPB. The wood must be debarked, because the bark contains more inhibitors, which prevents cement from hydration (Winkler 1998). These inhibitors are mostly in water soluble hemi-cellulose. The bark content of the raw material must not exceed 5%. The wood harvested in autumn or in winter contains less inhibitor (Alpar and Nádor, 2000). Logs harvested in other periods should be stored for two months. (Alpar, 2008)

The particles are mixed with Portland cement, chemicals and water. Conventionally water-glass is added to the mixture to accelerate the setting of Portland cement (Alpár, 2000). After blending a three layered mat is formed by two wind formers and one mechanical former.

The mats are piled and pressed together with steel plates in batches (Hadnagy, 1983). The fixed stocks are later placed for 8-10 hours in a curing chamber where the temperature is 70°C and the relative humidity is 80-85%. After this time the boards are self-bearing, but they have to be stored for two weeks until cement reaches its final strength. (Alpár and Nádor, 2000)

Typical composition of CBPB (Alpár, 1998):
- 20% wood particles
- 60% Portland cement
- 20% water and additives

Main properties of CBPB:
- 1200-1300 kg/m^3 density,
- 10 MPa bending strength (at 10% moisture content),
- 1-2.5% thickness swelling.

The aim of the present research was to develop CBPB which fulfills all the standard requirements from alternate raw materials.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

Raw materials used in experiments:
- Scots pine (*Pinus sylvestris*) particles
- I214 poplar (*Populus euramericana* cv. „I 214“) particles,
- CEM I 42.4 Portland cement,
- calcium-chloride ($CaCl_2$),
- calcium-formate ($C_2H_2CaO_4$),
- water-glass (Na_2SiO_3).

For the researches FALCO Zrt. bought I214 poplar pulpwood from winter harvest, and the logs were stored debarked for 2 months. The conventionally used Scots pine was treated in the same manner. Following this particles were made in the production line.

Before board production, laboratory hydration tests were made to examine the effect of cement hydration on different wood species and additives. Hydration was tested by measuring hydration temperature of the prepared samples during the first 24 hours of hydration

Table 1 Raw material requirements of water-glass (WG) added boards
Tablica 1. Količine sirovine za proizvodnju ploča s dodatkom vodenog stakla (WG)

	Surface layer raw materials for 1 board *Količina sirovine za površinski sloj jedne ploče*					
Mark / *Oznaka*	100SP_WG	80SP_WG	60SP_WG	40SP_WG	20SP_WG	0SP_WG
Scots pine, g / *borovina, g*	466	372	279	186	93	0
Populus I214, g / *topolovina I214, g*	0	85	171	256	342	427
Cement, g / *cement, g*	1027	1027	1027	1027	1027	1027
Water-glass, g / *vodeno staklo, g*	30	30	30	30	30	30
Water, g / *voda, g*	554	562	570	577	585	593
	Core layer raw materials for 1 board *Količina sirovine za središnji sloj jedne ploče*					
Mark / *Oznaka*	100SP_WG	80SP_WG	60SP_WG	40SP_WG	20SP_WG	0SP_WG
Scots pine, g / *borovina, g*	325	260	195	130	65	0
Populus I214, g / *topolovina I214, g*	0	61	122	182	243	304
Cement, g / *cement, g*	684	684	684	684	684	684
Water-glass, g / *vodeno staklo, g*	20	20	20	20	20	20
Water, g / *voda, g*	355	359	363	368	372	376

Table 2 Raw material requirements of calcium-chloride and calcium-formate (CC) added boards
Tablica 2. Količine sirovine za proizvodnju ploča s dodatkom kalcijeva klorida i kalcijeva formata (CC)

	Surface layer raw materials for 1 board *Količina sirovine za površinski sloj jedne ploče*					
Mark / *Oznaka*	100SP_CC	80SP_CC	60SP_CC	40SP_CC	20SP_CC	0SP_CC
Scots pine, g / *borovina, g*	466	372	279	186	93	0
Populus I214, g / *topolovina I214, g*	0	85	171	256	342	427
Cement, g / *cement, g*	1027	1027	1027	1027	1027	1027
Calcium-chloride and calcium-formate, g *kalcijev klorid i kalcijev format, g*	40	40	40	40	40	40
Water, g / *voda, g*	544	552	559	567	575	582
	Core layer raw materials for 1 board *Količina sirovine za središnji sloj jedne ploče*					
Mark / *Oznaka*	100SP_CC	80SP_CC	60SP_CC	40SP_CC	20SP_CC	0SP_CC
Scots pine, g / *borovina, g*	325	260	195	130	65	0
Populus I214, g / *topolovina I214, g*	0	61	122	182	243	304
Cement, g / *cement, g*	684	684	684	684	684	684
Calcium-chloride and calcium-formate, g *kalcijev klorid i kalcijev format, g*	27	27	27	27	27	27
Water, g / *voda, g*	348	352	357	361	365	369

with 15 min sampling frequency by an ALMEMO 8590-9 type data acquisition module. The maximum temperature and the time required for reaching this maximum temperature were noted and compared. Particles for the surface layer were used depending on their specific surface area. The ratios of compounds were the same as the recipe in board production (Table 1 and 2). The marks are set up as follows: percentage of Scots pine to I214 poplar – e.g. 60% of Scots pine and 40% of poplar makes 60SP - plus type of curing additive - WG for water-glass and CC for combination of calcium-chloride and calcium-formate. In this case the mark is: 60SP_WG or 60SP_CC depending on the additive.

During laboratory board production different ratios of wood species were used (100% - 80% - 60% - 40% - 20% - 0%) and from each type two boards were pressed parallel in one press to have more test pieces. The thickness was chosen for the most commonly used board thickness of 12 mm. The experiments were made with both types of additives: first with conventional water-glass and then with a 3% water based solution of a 3:1 mixture of calcium-chloride and calcium-formate (CC). Wood-cement ratio 1:2.6 was chosen. The moisture of the total mixture was 44%. During the research three layered boards were pressed from different particle sizes in the core (2-5 mm) and surface (<2 mm) layers. The ratio of the core and the surface layers were 30% - 40% - 30%.

The calculated amount of raw materials was measured on a balance with an accuracy of ±0.01 g. The raw material for the core and surface layers was blended separately by a mixer. The mat was formed manually into a frame with dimensions of 400 x 400 mm. The mats were pressed in a Siempelkamp laboratory press at specific pressure of 4.8 N/mm^2 and at room temperature for 14 hours. After this the boards were stored for two more weeks before being tested under standard climate conditions (65%, 20 °C). Longer pressing time was used to compensate the lack of climate in curing chamber.

Finally the most important physical and mechanical tests were made on the experimental boards. For each test 7 test pieces were cut from each board, so 14 test pieces were measured from each board type. Mechanical tests were made by an INSTRON 5566 universal material testing device. The tested features were: thickness swelling (EN 317:1998), density (EN 323:1995), bending strength (EN 310:1999), modulus of elasticity (EN 310:1999) and internal bond (EN 319:1998). The years of the above mentioned norms are the years of implementation of EU norms in Hungary.

3 RESULTS AND DISCUSSION
3. REZULTATI I DISKUSIJA

The results of preliminary hydration test are shown in Table 3. It can be concluded from these results that there is no disadvantageous effect of poplar on curing of cement, hence there is only a slight difference regarding T_{max}, and there is no difference regarding t_{Tmax}, so it is suitable to produce CBPB.

Table 4 presents a summary of the results of physical and mechanical tests. This will be followed by diagrams for detailed evaluation.

The changes of mechanical properties caused by the mixing ratio of two wood species are shown in Fig. 1 to 3. Each diagram shows the percentage of Scots pine to I214 poplar on the X axis: e.g. 60% means 60% of Scots pine and 40% of I214 poplar. The color of bars shows the additives: WG for water-glass and CC for combination of calcium-chloride and calcium-formate.

Table 3. Results of hydration test of analysed boards
Tablica 3. Rezultati hidratacijskog testa analiziranih ploča

Sample ID / *Redni broj uzorka*	1	2	3	4	5	6
I214 poplar**, g / *topolovina I214, g*	34	-	34	-	-	-
Scots pine**, g / *borovina, g*	-	41	-	41	-	-
Cement, g / *cement, g*	81	81	81	81	107	107
Water-glass, g / *vodeno staklo, g*	3	3	-	-	4	-
CC*, g	-	-	3	3	-	4
Water, g / *voda, g*	54	46	54	46	58	58
T_{max}, °C	29.3	25.8	29.9	26.7	29.6	32.6
$t_{T_{max}}$, min	75	75	75	75	855 (14.25h)	720 (12.0h)

* CC = 3% water based solution of a 3:1 mixture of calcium-chloride and calcium-formate / *CC – 3 %-tna vodena otopina smjese kalcijeva klorida i kalcijeva formata u omjeru 3:1;*
** technical dried mass with moisture content / *tehnički suha masa sa sadržajem vode*

By increase of the poplar ratio, the properties were generally also increased, although this tendency was not clear in every case. The maximum values were found at 40/60 and 20/80 mixing ratio of Scots pine/I214 poplar particles. The use of calcium-chloride and calcium-formate instead of water-glass improved the mechanical properties of the boards almost in every case.

The results show that by adding poplar the strength of the CBPB will increase, although in case of 100% of poplar the values show a little drop. These results are a bit surprising because the strength of poplar itself is usually below that of pine. The reason for the increase of strength lies in the shape of particles: the Scots pine has straight elements with smooth surface and the poplar has long, wavy and "hairy" elements so these can provide better matting and linking. When used, the solution of calcium-chloride and calcium-formate increased the mechanical properties of boards compared to those made with conventional water-glass.

The standard for CBPB (EN 634-2:2007) has the following requirements: minimum bending strength of

Table 4 Summarized results of mechanical tests
Tablica 4. Rezultati ispitivanja mehaničkih svojstava

Bending strength / *Savojna čvrstoća*, MPa						
Mark / *Oznaka*	100SP_WG	80SP_WG	60SP_WG	40SP_WG	20SP_WG	0SP_WG
MOR	11.60	11.36	12.70	14.09	13.27	13.48
St.Dev.	1.7828	1.3788	1.3834	1.1449	2.3405	1.4429
Mark /Oznaka	100SP_CC	80SP_CC	60SP_CC	40SP_CC	20SP_CC	0SP_CC
MOR	12.02	12.61	13.17	14.86	15.31	13.83
St.Dev.	1.4575	0.9153	2.5549	1.6030	1.2308	1.9513
Modulus of elasticity / *Modul elastičnosti*, GPa						
Mark / *Oznaka*	100SP_WG	80SP_WG	60SP_WG	40SP_WG	20SP_WG	0SP_WG
MOE	4975.315	5527.935	4928.413	5152.907	5032.9	5194.5
St.Dev.	603.032	347.672	715.911	393.095	649.228	576.890
Mark / *Oznaka*	100SP_CC	80SP_CC	60SP_CC	40SP_CC	20SP_CC	0SP_CC
MOE	5 228.66	5078.312	5097.013	5734.434	5838. 696	5062.716
St.Dev.	710.769	490.071	784.608	370.115	572.410	348.743
Internal bond / *Čvrstoća raslojavanja*, MPa						
Mark / *Oznaka*	100SP_WG	80SP_WG	60SP_WG	40SP_WG	20SP_WG	0SP_WG
IB	0.53	0.65	0.67	0.63	0.67	0.66
St.Dev.	0.0679	0.0888	0.1001	0.0465	0.0886	0.0636
Mark / Oznaka	100SP_CC	80SP_CC	60SP_CC	40SP_CC	20SP_CC	0SP_CC
IB	0.68	0.68	0.69	0.77	0.92	0.68
St.Dev.	0.0734	0.1144	0.0908	0.0886	0.0683	0.1032

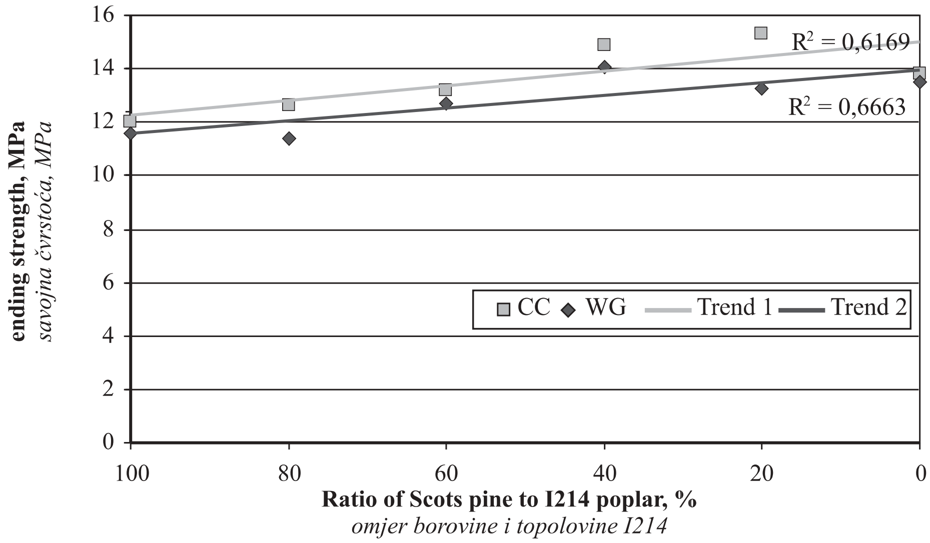

Figure 1 Bending strength of boards made from Scots pine and I214 poplar with regard to additive (WG or CC)
Slika 1. Savojna čvrstoća ploča izrađenih od borovine i topolovine I214 s različitim primjesama (WG ili CC)

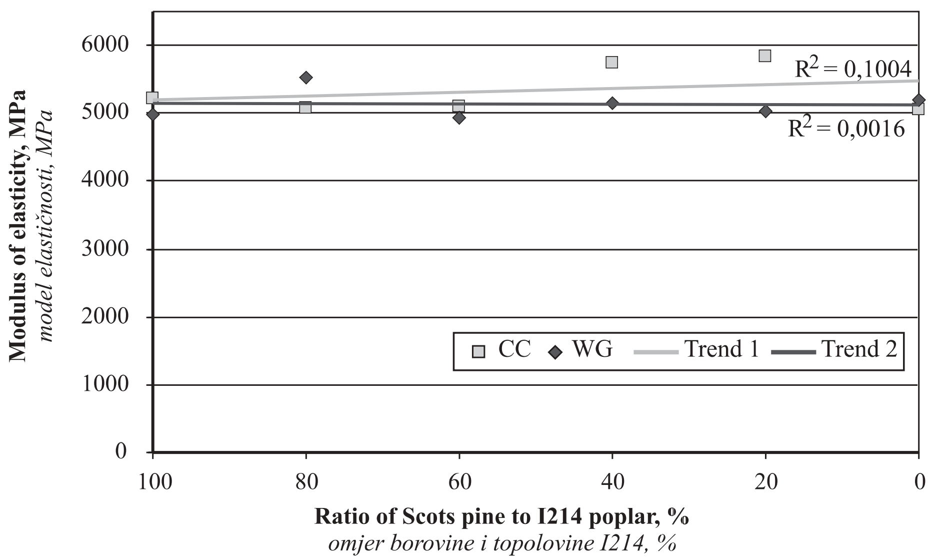

Figure 2 MOE of boards made from Scots pine and I214 poplar with addition of WG or CC
Slika 2. Modul elastičnosti ploča izrađenih od borovine i topolovine I214 s različitim primjesama (WG ili CC)

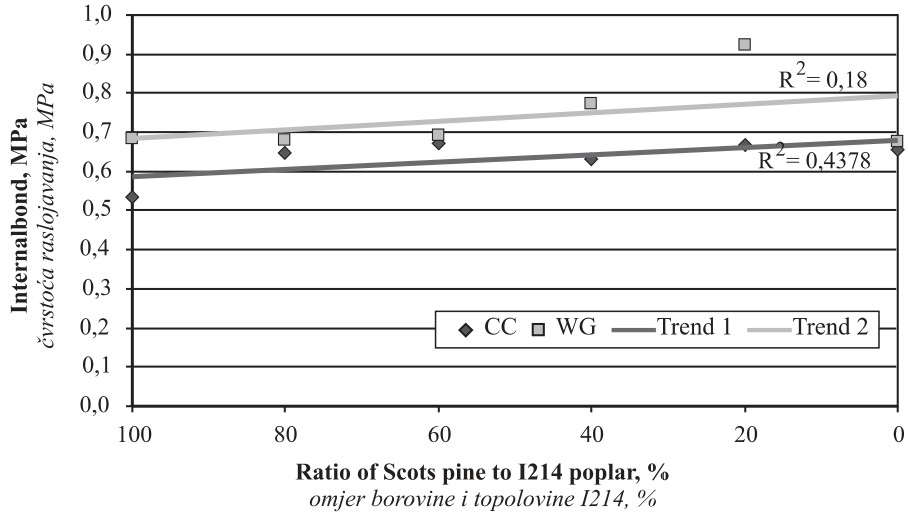

Figure 3 Internal bond of boards made from Scots pine and I214 poplar with addition of WG or CC
Slika 3. Čvrstoća raslojavanja ploča izrađenih od borovine i topolovine I214 s različitim primjesama (WG ili CC)

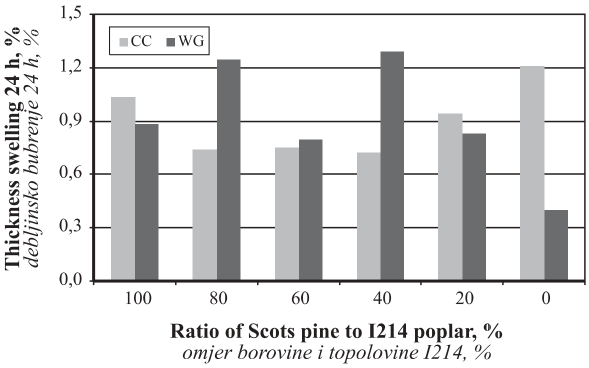

Figure 4 Thickness swelling of boards made from Scots pine and I214 poplar with addition of WG or CC
Slika 4. Debljinsko bubrenje ploča izrađenih od borovine i topolovine I214 s različitim primjesama (WG ili CC)

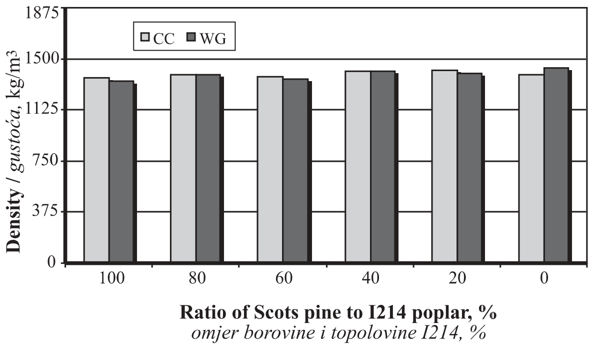

Figure 5 Density of boards made from Scots pine and I214 poplar with addition of water- glass or CC
Slika 5. Gustoća ploča izrađenih od borovine i topolovine I214 s različitim primjesama (WG ili CC)

9 MPa, minimum modulus of elasticity of 4500 MPa for the first class and 4000 MPa for the second class, and minimum internal bond of 0.5 MPa. These requirements were fulfilled by all experimental boards.

The changes of physical properties caused by the mixing ratio of two wood species are shown in Fig. 4 to 5. The density of the boards was around the standard requirement as desired. Regarding thickness swelling no tendencies were found, but all the values were much below the standard requirement (EN 634-2:2007) of maximum 1.5 %.

Based on this research it is recommended to replace or partly replace the expensive Scots pine with I214 poplar, because its use will result in the same quality of CBPB. It might be considered to replace water-glass with the combination of calcium-chloride and calcium-formate because this additive has increased the strength of the boards even in case of conventional Scots pine.

Before changing the technology, industrial-scale experiments should be made based on these laboratory results.

4 CONCLUSION
4. ZAKLJUČAK

During this research CBPB were made by using a mixture of Scots pine and I214 poplar in different mixing ratios and an alternate additive was also examined - the solution of calcium-chloride and calcium-formate. It can be concluded from the results that it is possible to produce CBPB from poplar with the same properties as, or even better than, from pine. The new additive has also improved satisfactorily the board properties. The reason for this is the better mineralization of wood elements and the hindering the sugars to be solved. The results also show economical advantages as poplar pulp wood was about 30% cheaper than Scots pine in Hungary at the time of the research.

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