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I-PAN

INNOVATIVE POPLAR LOW DENSITY STRUCTURAL PANEL

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D3.3 Results from the synthesis and characterisation of resins

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Document information

Abstract

In the framework of I-PAN, CHIMAR develops a technology for producing an innovative resin suitable for bonding poplar strands and recycled wood to form light weight OSB (LSB) panels for structural use.

The R&D objectives for the innovative resin system are:

- Curing temperature lower than that of the conventional resin systems by up to 10%.
- Compensation of strand moisture contents higher than 3.5%.
- To provide panels with formaldehyde emissions satisfying the most stringent European Standards as per EN 13986.

This report details the work performed by CHIMAR in the synthesis and characterisation of resins and their subsequent evaluation in the production of lab scale LSB.

Keywords

Poplar, wood, OSB, wood-based panels, engineered wood, binder, adhesive, resin, formaldehyde

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* Abbreviations of editor/contributor name

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND DEFINITIONS

Table 1 - List of abbreviations

OSB	Oriented Strand Board
LSB	Lightweight Strand Board
MUF	Melamine Urea Formaldehyde
MUPF	Melamine Urea Phenol Formaldehyde
PF	Phenol Formaldehyde
IB	Internal Bond
TS	24h Thickness swelling
MOR	Modulus of Rupture
MOR-B	Bond Durability - Modulus of Rupture after 2h boiling
V100	IB after 2h boiling and drying
Perforator	Formaldehyde content as per EN 120
ANOVA	Analysis of Variance
MR	Molar Ratio of Resins

1 INTRODUCTION

I-PAN project aims at providing novel and environmentally friendly solutions in the field of engineered wood boards (or wood-based panels) and particularly in Oriented Strand Boards (OSB) manufacturing process with the target to reach the higher level functional characteristics of Lightweight Strand Boards (LSB). OSB/LSB is a type of wood-based panel consisting of strands of wood pressed together in layers and bonded with a synthetic resin. The wood species used in OSB manufacture include both softwood and hardwood. The resin types typically used include Phenol formaldehyde (PF), Melamine fortified Urea Formaldehyde (MUF) or isocyanate (pMDI). In the I-PAN project a breakthrough lightweight OSB panel will be developed, comprising 50% of its volume of recycled wood and for the remaining 50% of poplar wood by using the upper part of the poplar tree that is commonly underused. To this purpose, a novel OSB manufacturing process will be developed and an innovative binder system will be formulated thus allowing the reduction of energy requirements during the drying and pressing process of OSB manufacture, the minimization of VOC emissions and the reduction of the overall production cost.

In the framework of I-PAN, CHIMAR develops a technology for producing an innovative resin suitable for bonding poplar strands and recycled wood to form light weight OSB panels for structural use. The innovative resin is based on formaldehyde and will be of the aminoplastic (urea-formaldehyde, urea-melamine-formaldehyde/melamine-urea-formaldehyde, melamine-formaldehyde), or phenolic (phenol-formaldehyde) type or a combination of these types and it will be combined with a suitable cross-linking agent and possibly with a suitable formaldehyde catcher.

The R&D objectives for the innovative resin system are:

- Curing temperature lower than that of the conventional resin systems by up to 10%.
- Compensation of strand moisture contents higher than 3.5%.
- To provide panels with formaldehyde emissions satisfying the most stringent European Standards as per EN 13986.

In what follows, the work performed by CHIMAR comprising the synthesis and characterisation of resins and their subsequent evaluation in the production of lab scale LSB is described. Since this work was based on the findings of previous deliverable D3.2, a summary of D3.2 is first given.

2 SUMMARY OF THE WORK PERFORMED IN D3.2

In the framework of D3.2, CHIMAR work included the development of suitable resin precursors, their application in preliminary resin synthesis and their subsequent evaluation in the production of lab scale LSB. At first both the lab resin synthesis process and OSB lab preparation were calibrated. Both strands from Bulgarian spruce and poplar strands received from IMAL/IBL were used to produce the light weight OSB. The resin precursors were based on urea, formaldehyde, melamine and phenol. Suitable formulations of MUF and MUPF type resins were developed and samples of them were produced at CHIMAR lab and tested. The binder systems included special hardeners and crosslinkers to enhance the performance of the main binder and allow the reduction of the press temperature. Prior to panel production the strands were dried with target final moisture content around 3-4%. Panels with reduced density were prepared and their mechanical strength, water resistance and emission potential were tested. The effect of viscosity of the binder resin was evaluated. Optimization was performed to adjust the properties of the panels as well as their formaldehyde emission potential.

The results indicated that it is feasible to manufacture at laboratory scale light weight boards (density level of ~500kg/m^3) with poplar strands of I-214 clone supplied by the I-PAN partners, which meet the standard requirements for OSB/3 grade as well as the E1 formaldehyde class. The press temperature was reduced by more than 10% without increasing the press cycle thus meeting the target of lower energy demand.

3 CONSIDERATIONS AND METHODS

The OSB boards developed within I-PAN are prepared out of poplar strands made from a new fast-growing poplar tree species namely I-214 clone, which is grown in several European countries. Additionally the upper part of the tree log and the tree branches are mainly used for the preparation of the strands.

It should be pointed out that the laboratory strand boards prepared have actually random-orientated strands rather than oriented. Therefore, further to the typical test methods applied as per EN 300 - IB, TS, MOR and V100, the ***bond durability*** test (MOR-B), according to Canadian standard CSA 0437-93 on OSB and Waferboard, was also performed. The said CSA contains further to the O-1 and O-2 grades also the R-1 grade i.e. Random strand board that is more related to the laboratory panels produced.

The experimental study carried out by CHIMAR and reported herein included the verification of the results obtained in the previous Task 3.2. Furthermore, the effect of reduced board density (in the range of 450-500kg/m^3) on the overall performance of the LSB was studied. The deterioration of the board properties due to the reduced density of the LSB was compensated by increasing the resin loading. The lowest possible resin addition at the lowest possible viscosity was examined.

Further experiments were done with a new batch of strands received from the partners (IBL, IMAL). These experiments comprised using other binder type (as compared to previous experiments) and studying the binder parameters like reactivity.

The main target of the work that is presented herein is to obtain panels with the desired properties/performance and low formaldehyde emission levels.

4 EXPERIMENTAL STUDY

The raw materials used were:

- Poplar strands delivered by IBL/IMAL
- Resins of MUPF or PF type produced in CHIMAR laboratory using conventional raw materials
- Hardeners, conventional and special type, prepared in CHIMAR lab
- Cross-linking agents, prepared in CHIMAR lab
- Formaldehyde catchers/scavengers prepared in CHIMAR lab
- Paraffin wax from a Greek producer.

The first objective addressed was the verification of the results obtained with the best performing binder system in the production of LSB. An MUPF resin with 30% melamine and 3% phenol and overall molar ratio F:[$(NH_2)_2$+Ph]=0.96:1.00 was prepared in CHIMAR lab and tested. It was then applied either alone or in combination with two different formaldehyde catchers in the production of one layer LSB, so as to ensure a formaldehyde content of LSB well below the E1 class limit. The typical properties of the resin are depicted in the following table.

Table 2: *Resin properties*

Resin type	MUPF
Viscosity, 25^oC, cP	230
pH, 25^oC,	9.65
Water Tolerance, 25^oC, ml/ml	1: 0.50
Solids, 2g 2h 120^oC, %	64.30
Gel time, 3.5% $(NH_4)_2SO_4$, s	73

The production details and settings of the one layer strand boards with random orientation are shown in the next table.

Table 3: *OSB production details*

Board Dimensions, cm	43 x 43 x 1.6
Target Density, kg/m^3	500
Target board moisture, %	6.5
Press Factor, s/mm	12
Press Temperature, ^oC	180
Wood Source	Poplar IBL/IMAL
Resin Factor, % solid on dry wood	12
Paraffin Level, % solid on dry wood	1.0
Hardener Type and Level, % solid on solid resin	HR-2, 3.5
Crosslinker Type and Level, % dry on liquid resin	CR-1, 9.0
Formaldehyde Catcher	FC-1, FC-2
Target mat moisture, %	10.5
Strands initial target moisture, %	3.5

The panels obtained were subjected to the full range of tests – IB, TS, V100, MOR, MOR-B and perforator test. The average testing values are summarized in the next table.

Table 4: *OSB Testing results*

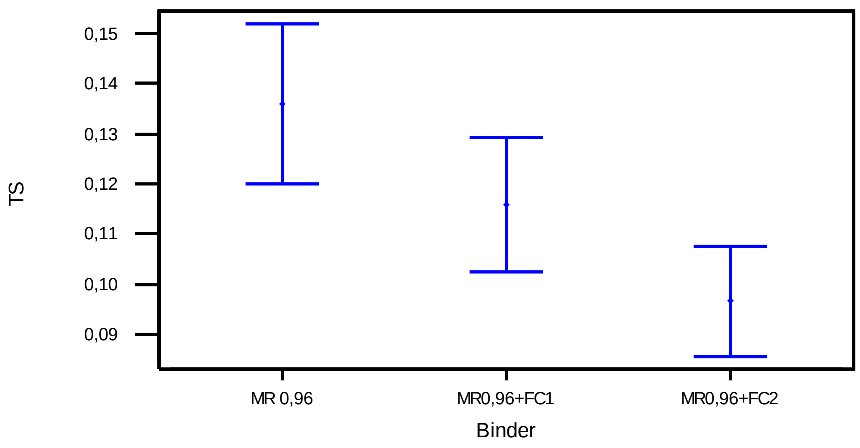
Press temperature, °C	180		
Press cycle, s/mm	12		
Hardener HR-2 level, %	3.5		
Crosslinker CR-1 level, %	9.0		
Binder system	MUPF MR 0.96	MUPF MR0.96+FC1	MUPF MR0.96+FC2
Thickness, mm	16.03	16.05	16.08
Density, kg/m³	499	509	508
IB, MPa	0.34	0.35	0.24
V100, MPa	0.14	0.12	0.10
TS, %	12.06	12.34	12.28
MOR, MPa	11.36	10.76	9.56
MOR-B, MPa	6.53	6.24	5.26
Perforator, mg/100g	5.39	4.36	4.03

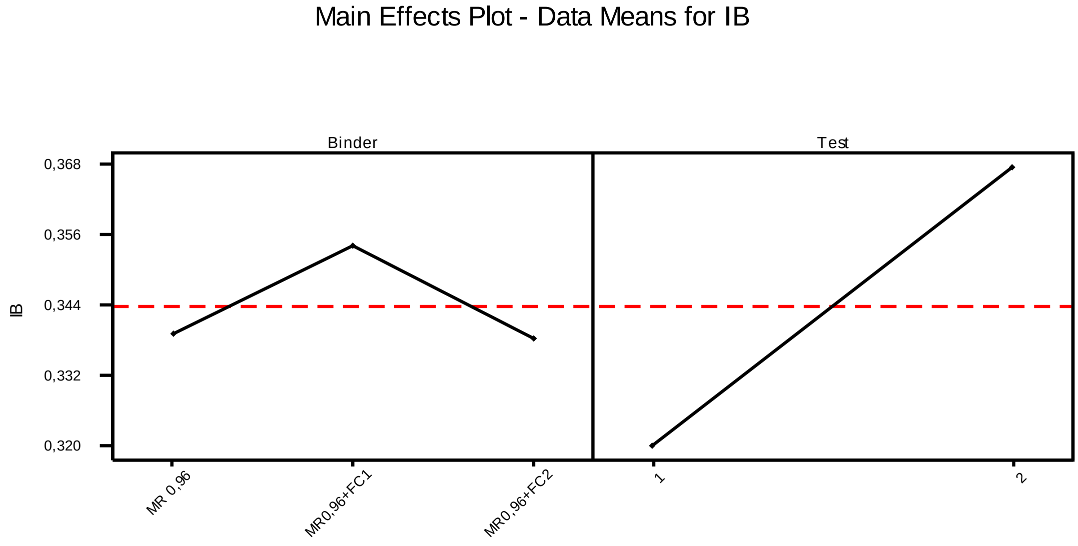
The results obtained from the ANOVA performed on the OSB testing values are the following:

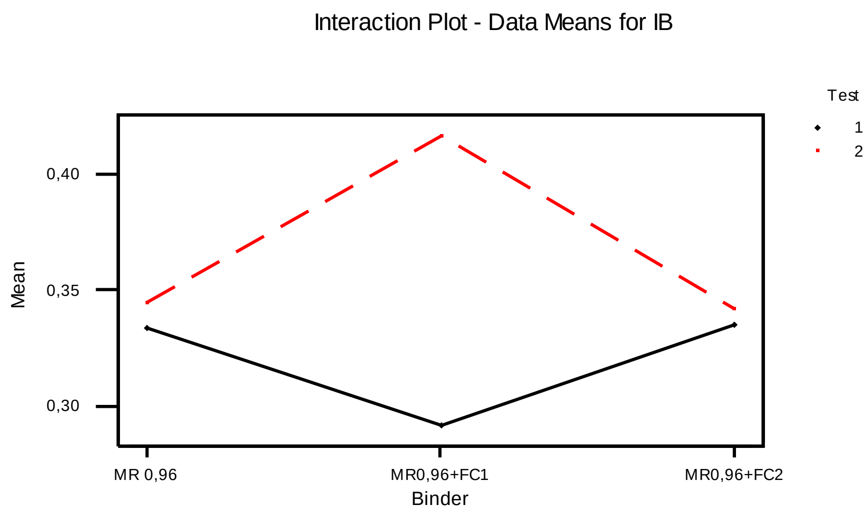
```
Analysis of Variance for IB, using Adjusted SS for Tests

Source        DF    Seq SS     Adj SS     Adj MS        F      P
Binder         2  0,001906   0,001906   0,000953     0,10  0,904
Test           1  0,020544   0,020544   0,020544     2,17  0,151
Binder*Test    2  0,026872   0,026872   0,013436     1,42  0,257
Error         30  0,283733   0,283733   0,009458
Total         35  0,333056
```

None of the factors examined is significant at 95% confidence interval for the IB of the panels.

Internal plot for Mean IB at 95% confidence interval





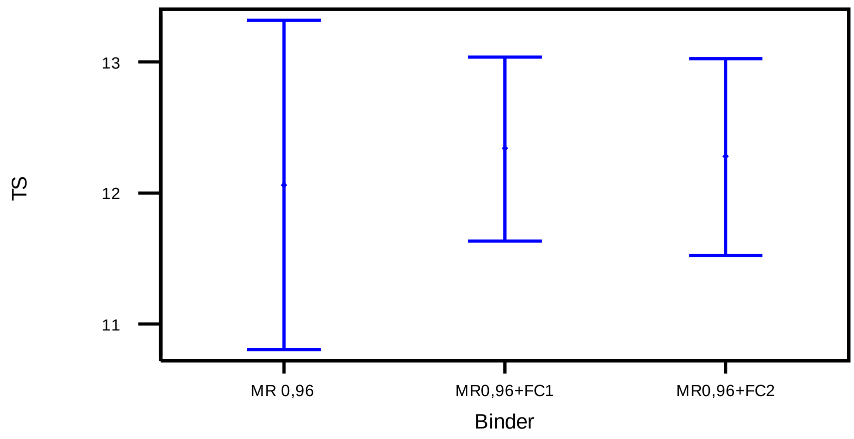


Analysis of Variance for TS, using Adjusted SS for Tests

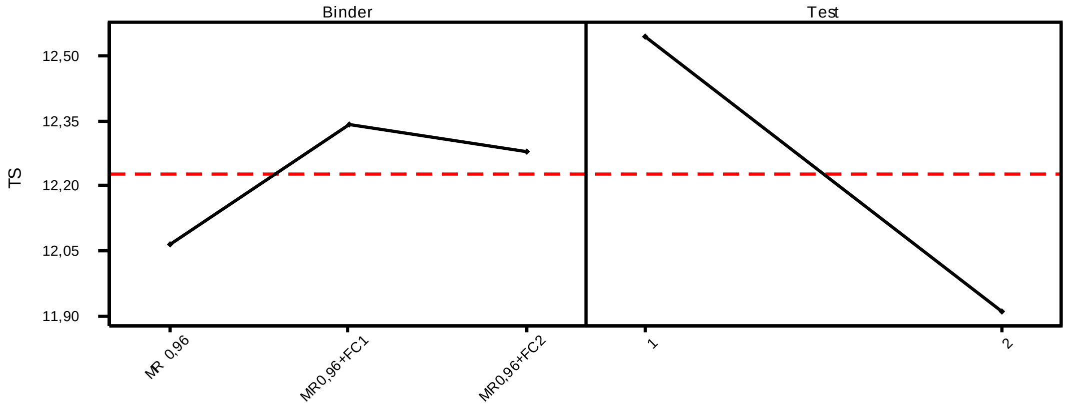
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Binder	2	0,503	0,503	0,252	0,13	0,878
Test	1	3,674	3,674	3,674	1,91	0,178
Binder*Test	2	10,000	10,000	5,000	2,59	0,091
Error	30	57,833	57,833	1,928		
Total	35	72,009				

Neither the binder type nor the number of trial is significant at 95% confidence interval for the thickness swelling of the LSB produced.

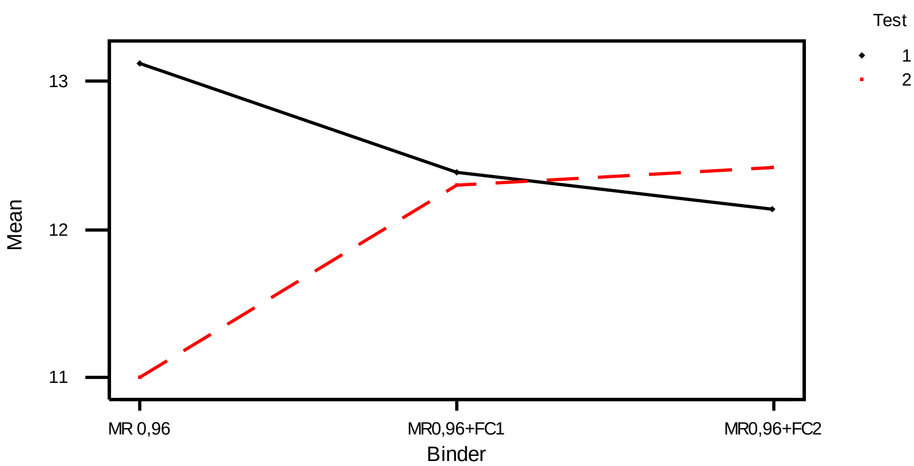
Internal plot for Mean TS at 95% confidence interval



Main Effects Plot - Data Means for TS



Interaction Plot - Data Means for TS

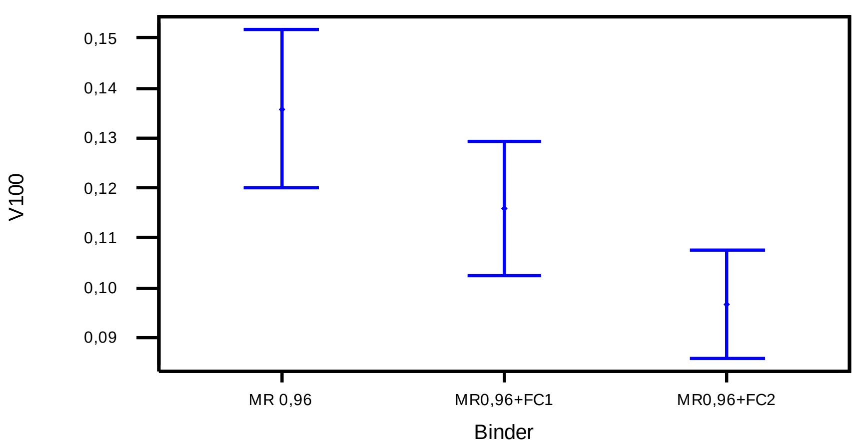


Analysis of Variance for V100, using Adjusted SS for Tests

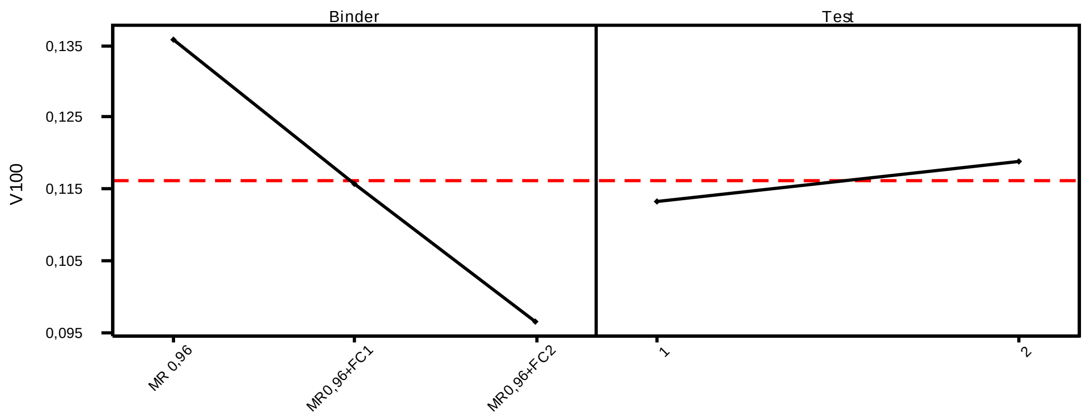
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Binder	2	0,0092056	0,0092056	0,0046028	9,39	**0,001**
Test	1	0,0002778	0,0002778	0,0002778	0,57	0,457
Binder*Test	2	0,0000722	0,0000722	0,0000361	0,07	0,929
Error	30	0,0147000	0,0147000	0,0004900		
Total	35	0,0242556				

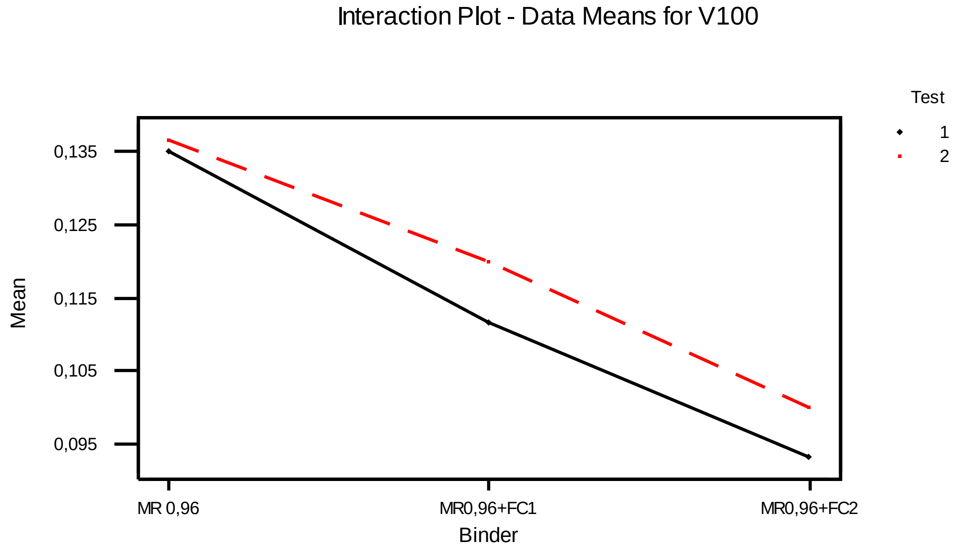
Only the binder **is significant** at 95% confidence interval (P<0.050) for the V100 of the panels produced. There is no interaction with the number of trial.

Internal plot for Mean V100 at 95% confidence interval



Main Effects Plot - Data Means for V100

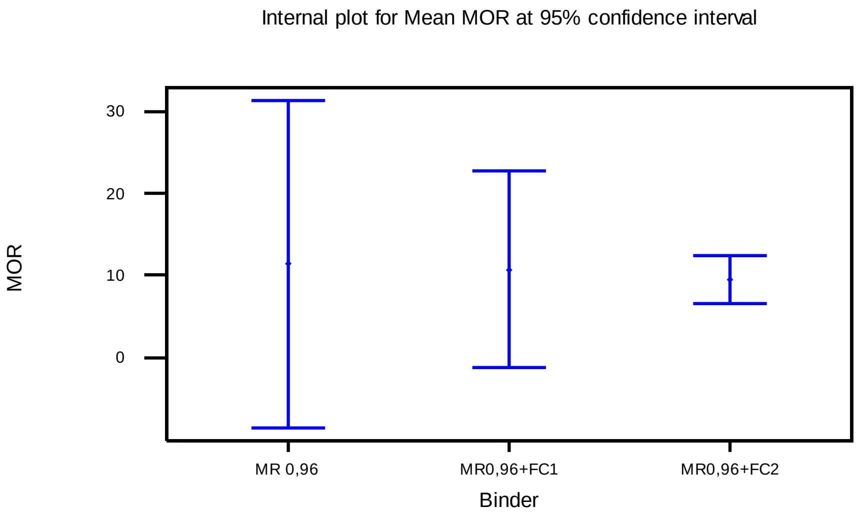


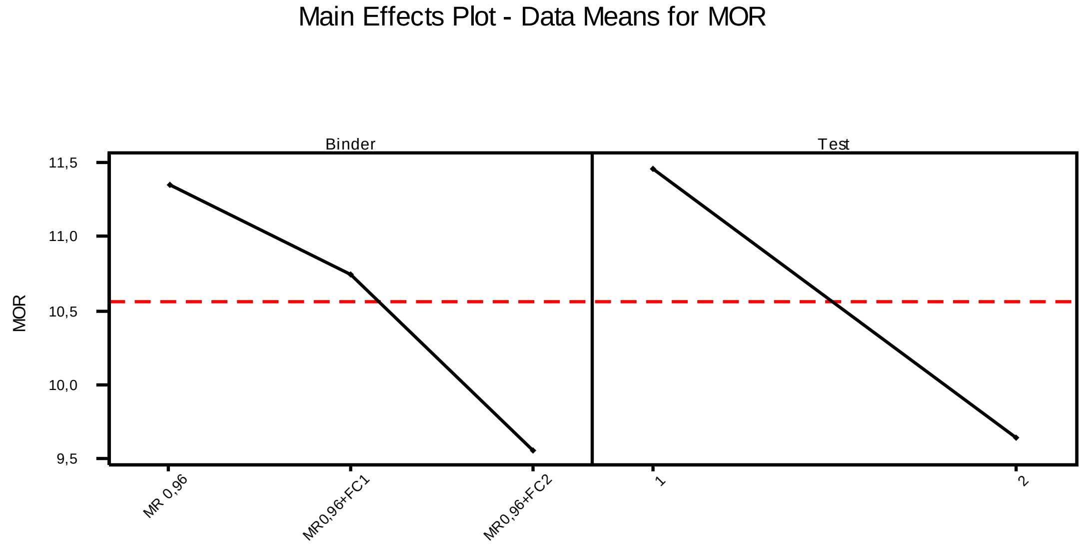


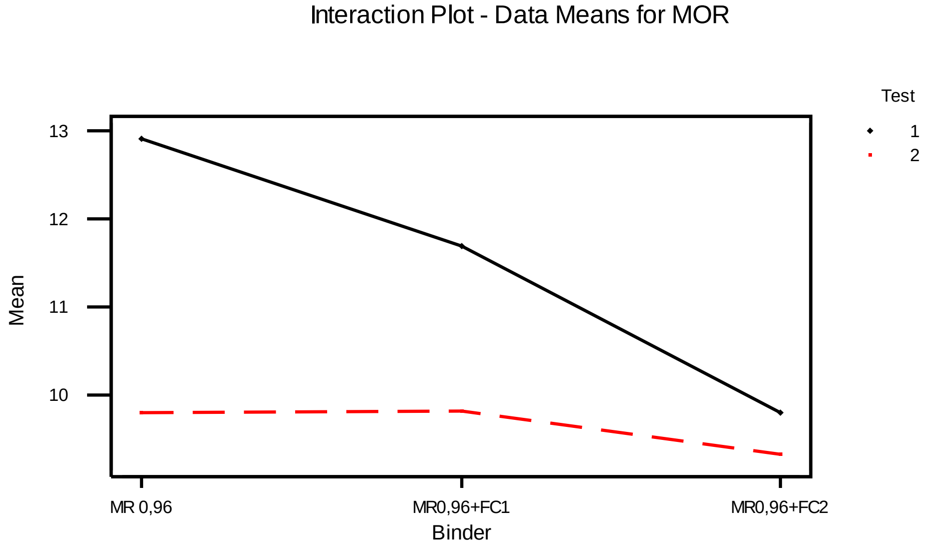
Analysis of Variance for MOR, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Binder	2	3,3400	3,3400	1,6700	1,87	0,348
Test	1	5,0051	5,0051	5,0051	5,61	0,141
Error	2	1,7852	1,7852	0,8926		
Total	5	10,1303				

None of the factors is significant for the MOR at 95% confidence interval.





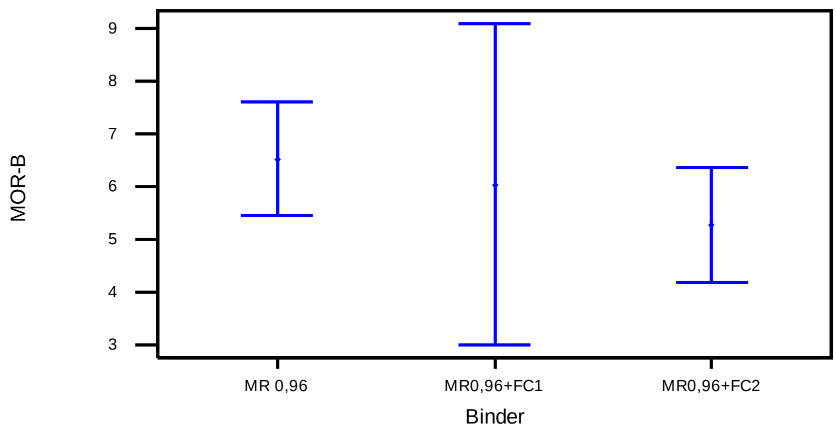


Analysis of Variance for MOR-B, using Adjusted SS for Tests

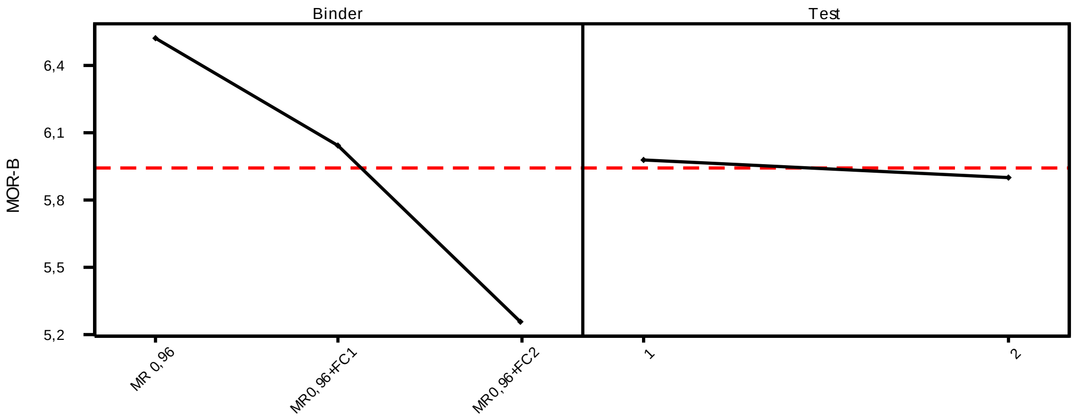
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Binder	2	3,286	3,286	1,643	0,77	0,504
Test	1	0,018	0,018	0,018	0,01	0,931
Binder*Test	2	1,003	1,003	0,501	0,24	0,798
Error	6	12,802	12,802	2,134		
Total	11	17,108				

At 95% confidence interval, none of the factors examined is significant for the MOR-B.

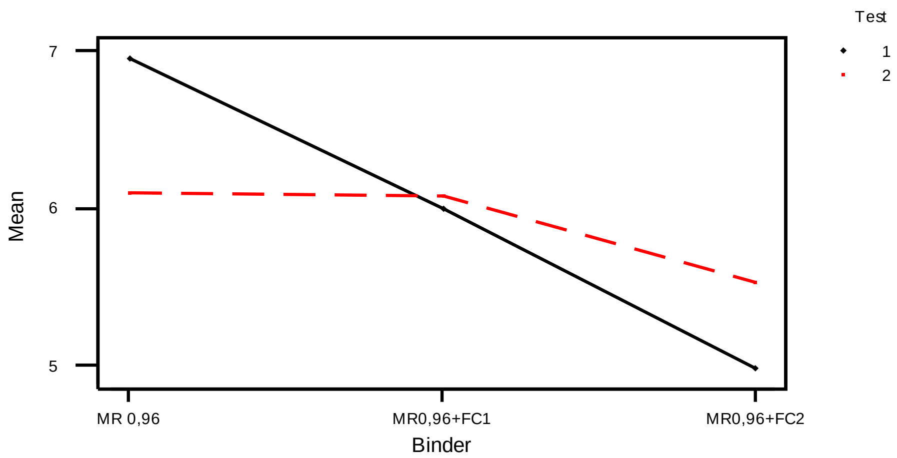
Internal plot for Mean MOR-B at 95% confidence interval



Main Effects Plot - Data Means for MOR-B



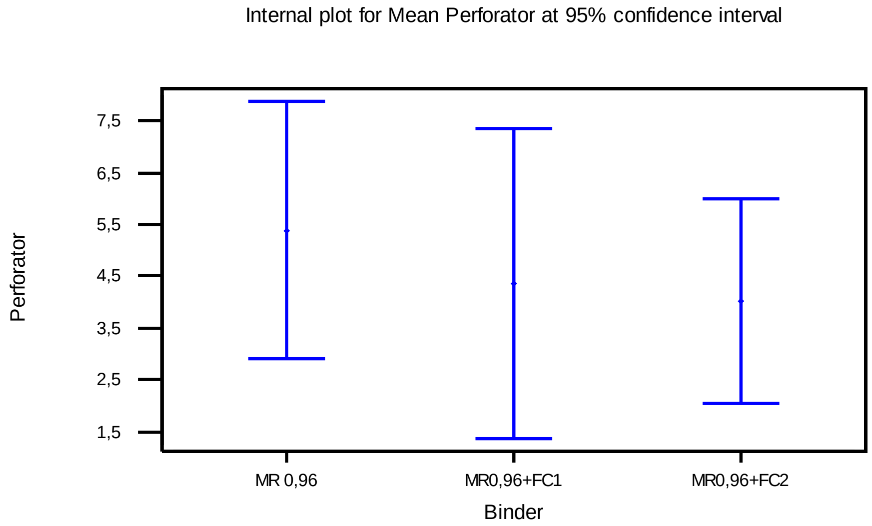
Interaction Plot - Data Means for MOR-B

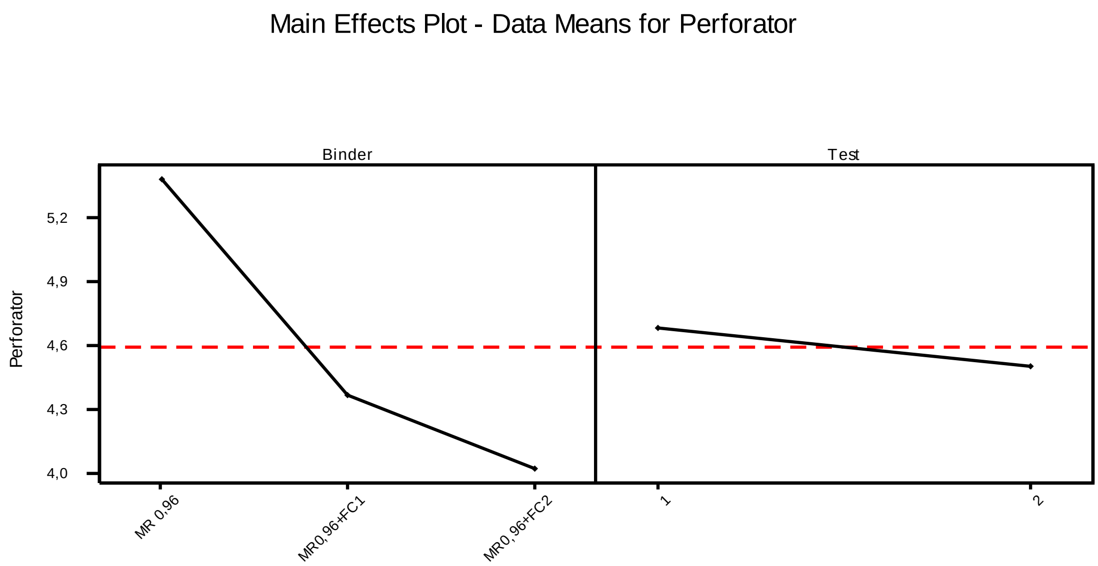


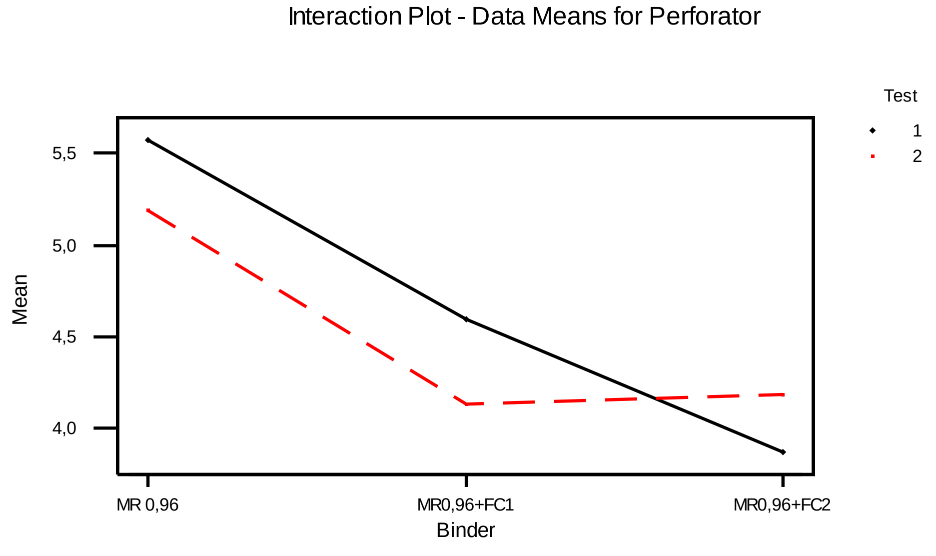
Analysis of Variance for Perforator, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Binder	2	2,00373	2,00373	1,00187	10,88	0,084
Test	1	0,05042	0,05042	0,05042	0,55	0,536
Error	2	0,18413	0,18413	0,09207		
Total	5	2,23828				

Neither the binder nor the test number is significant at 95% confidence interval for the formaldehyde content of the LSB panels produced.







The testing results indicate that there is statistically significant difference between the systems tested only in the case of V100. However, the systems with lower formaldehyde content (due to the application of formaldehyde scavenger), had lower values and did not meet the OSB/3 (EN300) standard requirements. Since the formaldehyde content of all systems was well below the E1 class limit, the system without scavenger addition was selected for the next experiments.

Comparing the results of the binder system without the formaldehyde scavenger with those of the similar binder system as tested in the work reported in D3.2, it was seen that there is a satisfactory repeatability in the lab scale production of poplar LSB (see Table 5).

Table 5: *Comparison of properties of OSB panels bonded with MUPF resin MR 0.96*

Press temperature, °C	180	
Hardener HR-2 level, %	3.5	
Crosslinker CR-1 level, %	9.0	
Binder system MR 0.96	Old (D3.2)	New (D3.3)
Thickness, mm	16.05	16.03
Density, kg/m^3	488	499
IB, MPa	0.38	0.34
V100, MPa	0.12	0.14
TS, %	14.17	12.06
MOR, MPa	15.59	11.36
MOR-B, MPa	6.25	6.53
Perforator, mg/100g	6.58	5.39

The next step in CHIMAR research work was the evaluation of the effect of density on the properties of the LSB and the optimization of panel production so as to retain the properties of the panels obtained in the standard range. Thus the binder system with MUPF, hardener and crosslinker used in the test reported above were applied in the production of LSB panels with a gradual decrease of the density, i.e. 500, 475 and 450kg/m^3, while the resin loading was always the same at 12% w/w dry resin on dry wood.

The production details and settings of LSB panels are depicted in the next table.

Table 6: *OSB production details*

Board Dimensions, cm	43 x 43 x 1.6
Target Density, kg/m^3	500, 475, 450
Target board moisture, %	6.5
Press Factor, s/mm	12
Press Temperature, ^{o}C	180^{o}C
Wood Source	IBL/IMAL
Resin Factor, % solid on dry wood	12
Paraffin Level, % solid on dry wood	1.0
Hardener Type and Level, % solid on solid resin	HR-2, 3.5
Crosslinker Type and Level, % dry/dry resin	CR-1, 9
Target mat moisture, %	10.5
Strands initial target moisture, %	3.5

The properties of the panels are summarised in the table below.

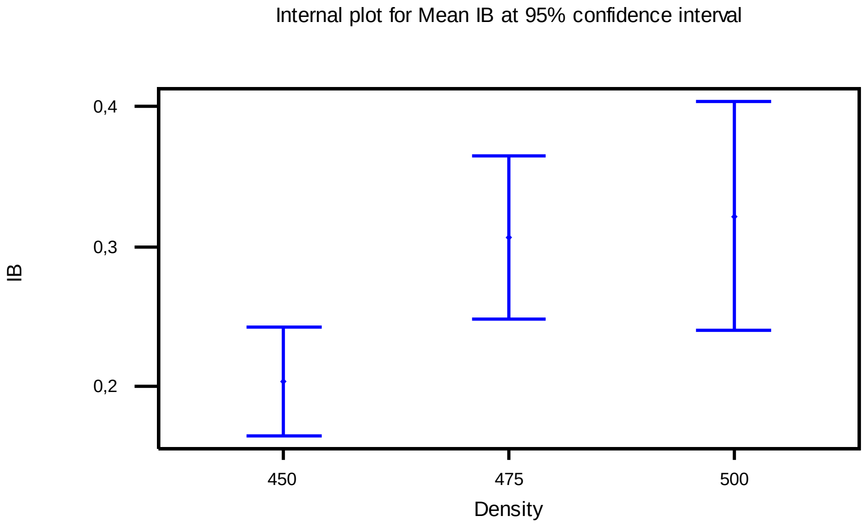
Table 7: *OSB Testing results*

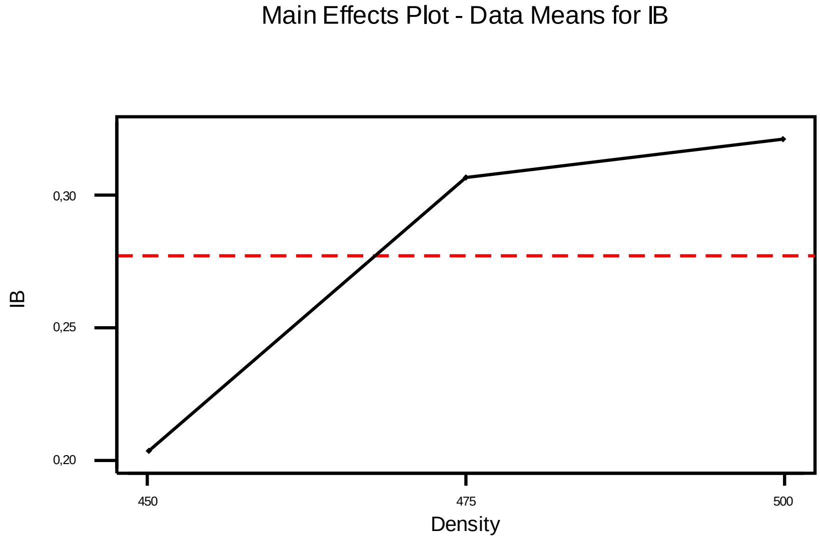
Press temperature, ^{o}C	180		
Press cycle, s/mm	12		
Hardener HR-2 level, %	3.5		
Crosslinker CR-1 level, %	9.0		
Target density, kg/m^3	500	475	450
Thickness, mm	16.10	16.12	16.09
Density, kg/m^3	495	480	445
IB, MPa	0.32	0.31	0.20
V100, MPa	0.14	0.11	0.08
TS, %	12.07	12.59	13.84
MOR, MPa	16.3	13.2	10.8
MOR-B, MPa	6.07	5.65	4.75
Perforator, mg/100g	5.9	6.2	6.5

ANOVA was performed on the OSB testing values and the results obtained are the following:

```
Analysis of Variance for IB, using Adjusted SS for Tests

Source      DF    Seq SS    Adj SS    Adj MS      F      P
Density      2  0,049811  0,049811  0,024906   7,11  0,007
Error       15  0,052550  0,052550  0,003503
Total       17  0,102361
```

The density of LSB **is significant** (P<0.050) at 95% confidence interval for the IB of the panels produced.



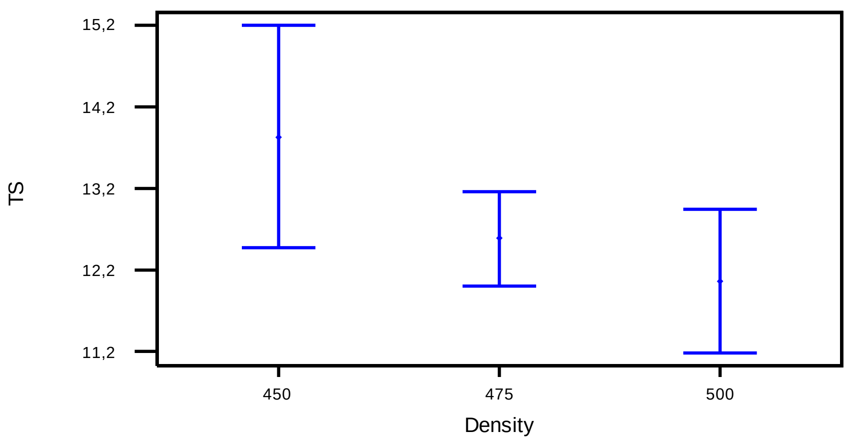


Analysis of Variance for TS, using Adjusted SS for Tests

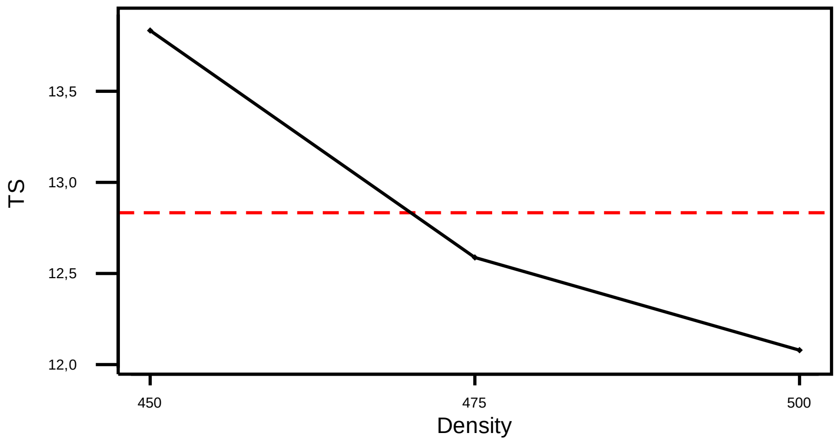
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Density	2	9,8658	9,8658	4,9329	5,48	**0,016**
Error	15	13,5090	13,5090	0,9006		
Total	17	23,3748				

For the thickness swelling of the LSB the density is a **significant** factor (P<0.050) at 95% confidence interval.

Internal plot for Mean TS at 95% confidence interval



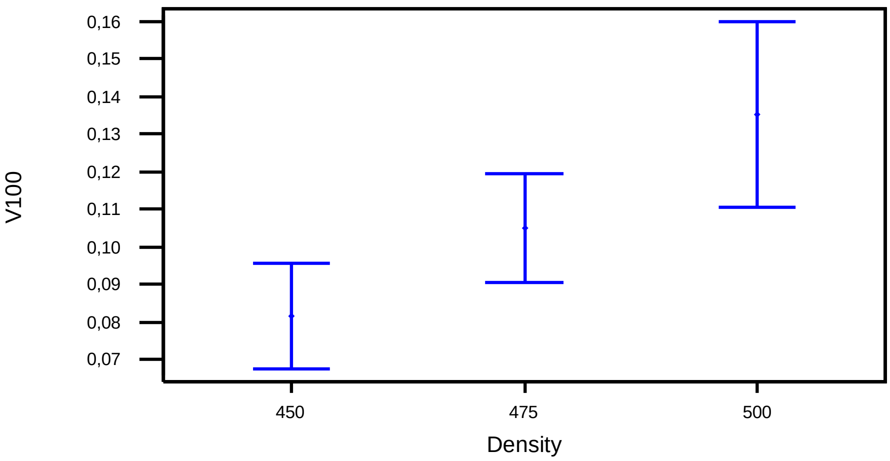
Main Effects Plot - Data Means for TS



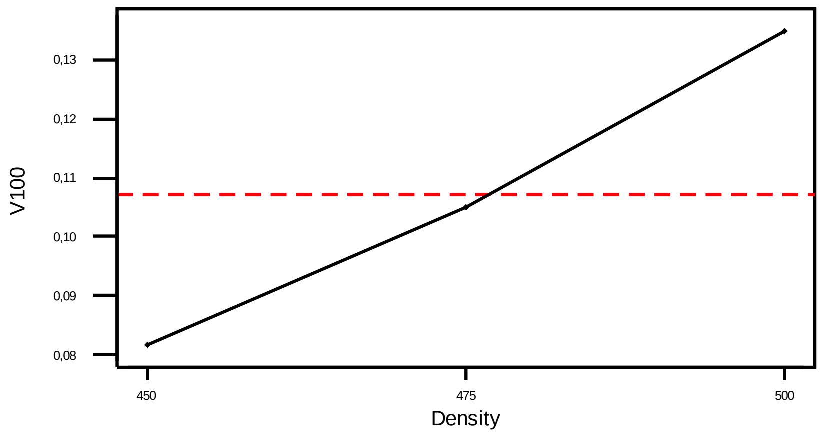

```
Analysis of Variance for V100, using Adjusted SS for Tests

Source        DF     Seq SS     Adj SS     Adj MS       F      P
Density        2  0,0085778  0,0085778  0,0042889   14,04  0,000
Error         15  0,0045833  0,0045833  0,0003056
Total         17  0,0131611
```

For the V100 of the LSB the density is a **significant** factor (P<0.050) at 95% confidence interval.

Internal plot for Mean V-100 at 95% confidence interval



Main Effects Plot - Data Means for V100

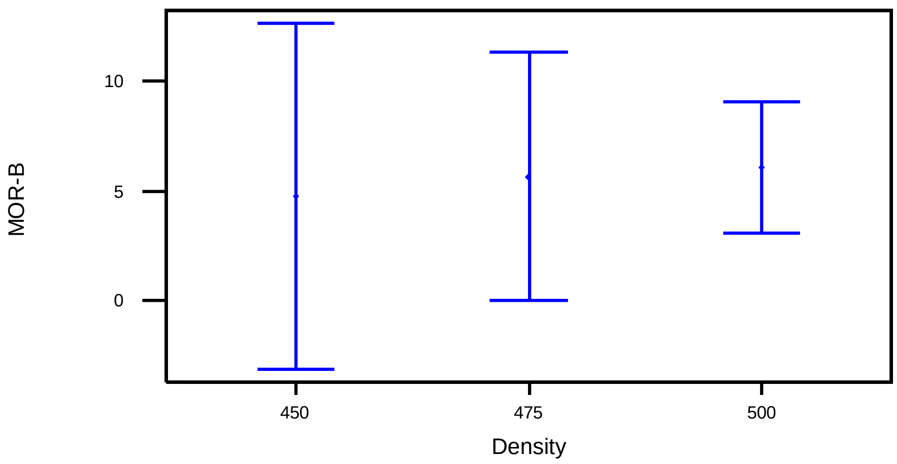


Analysis of Variance for MOR-B, using Adjusted SS for Tests

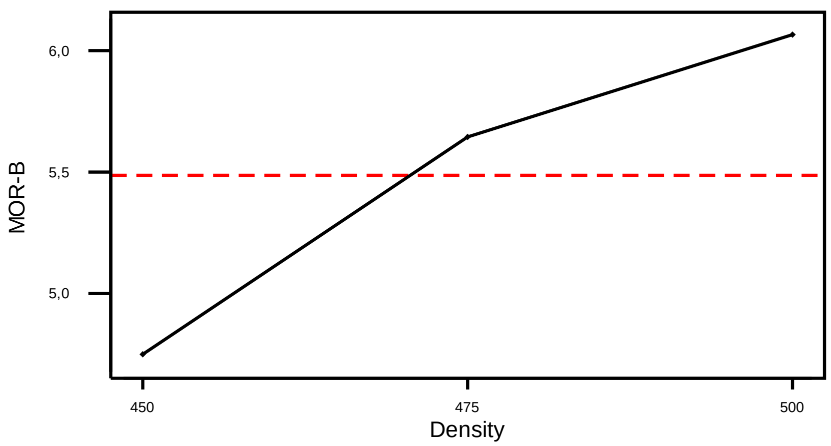
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Density	2	1,8044	1,8044	0,9022	2,12	0,266
Error	3	1,2753	1,2753	0,4251		
Total	5	3,0797				

The density of panels is not a significant factor at 95% confidence interval for the MOR-B of the LSB.

Internal plot for Mean MOR-B at 95% confidence interval

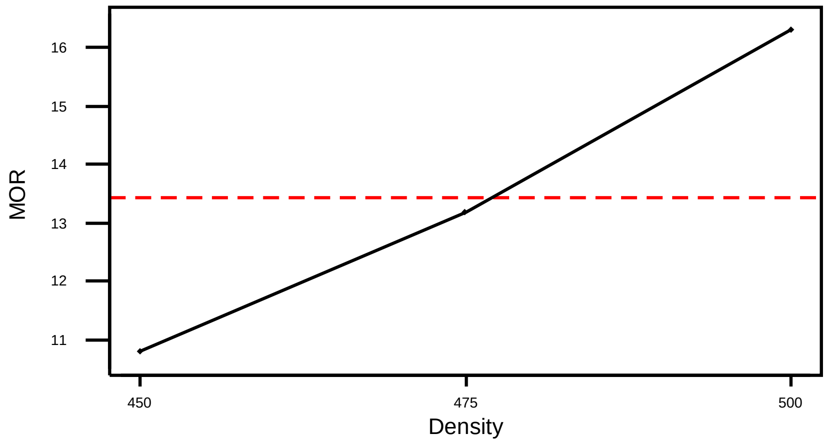


Main Effects Plot - Data Means for MOR-B

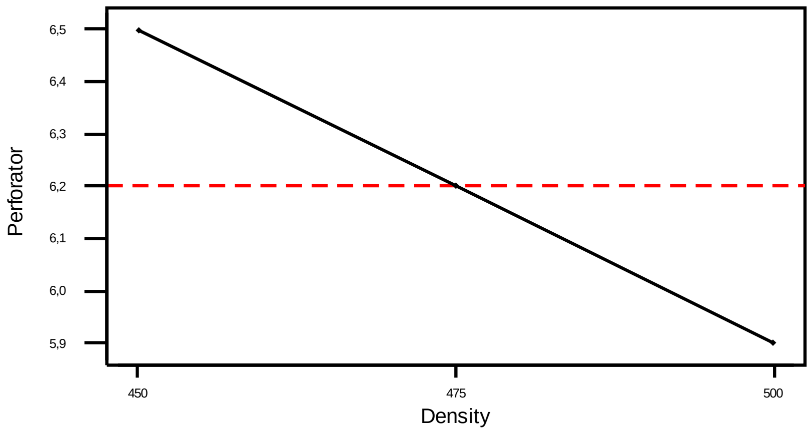


As the testing values for MOR and Perforator were not sufficient for statistical analysis, only the main effect plots are shown below.

Main Effects Plot - Data Means for MOR



Main Effects Plot - Data Means for Perforator



As expected, the testing results and their statistical analysis indicated that the lower the density, the worse the board property values. When the density was reduced to 475kg/m^3 some of the properties were still acceptable, while at 450kg/m^3 almost all properties did not meet the standard requirements. Therefore, it was considered that a slight increase of resin loading could compensate the drop of properties for the density of 475kg/m^3, while for the 450kg/m^3 density the increase in resin loading should be larger.

Thus in the next experiment, LBS panels were produced with a target density of 475kg/m^3 and two different resin loading levels: 12 and 13% w/w dry resin on dry wood. The MUPF binder system used in the previous trials was applied here too. The LSB production settings are summarised in the next table.

Table 8: *OSB production details*

Board Dimensions, cm	43 x 43 x 1.6
Target Density, kg/m^3	475
Target board moisture, %	6.5
Press Factor, s/mm	12
Press Temperature, ^{o}C	180^{o}C
Wood Source	IBL/IMAL
Resin Factor, % solid on dry wood	12 and 13
Paraffin Level, % solid on dry wood	1.0
Hardener Type and Level, % solid on solid resin	HR-2, 3.5
Crosslinker Type and Level, % dry/dry resin	CR-1, 9
Target mat moisture, %	10.5
Strands initial target moisture, %	3.5

The properties of the panels are summarised in the next table.

Table 9: *OSB Testing results*

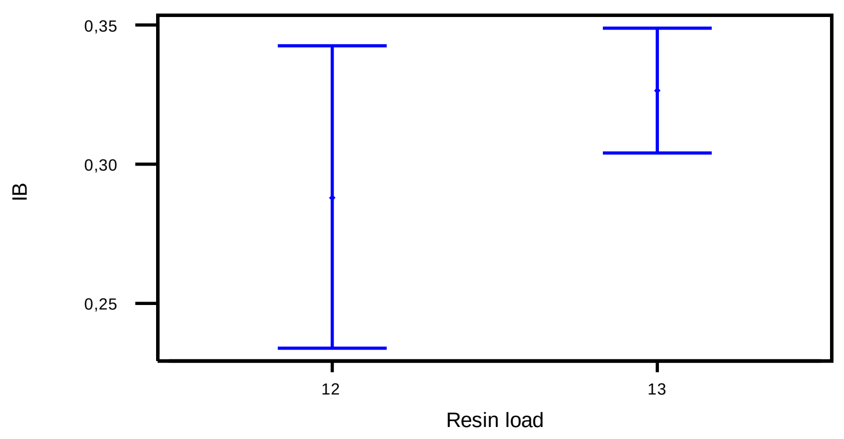
Press temperature, ^{o}C	180	
Press cycle, s/mm	12	
Hardener HR-2 level, %	3.5	
Crosslinker CR-1 level, %	9.0	
Target density, kg/m^3	475	
Resin Factor, % dry/dry wood	12	13
Thickness, mm	16.10	16.09
Density, kg/m^3	472	477
IB, MPa	0.29	0.33
V100, MPa	0.12	0.15
TS, %	12.33	12.47
MOR, MPa	12.35	13.80
MOR-B, MPa	5.63	6.26
Perforator, mg/100g	6.23	5.84

The ANOVA results obtained are the following:

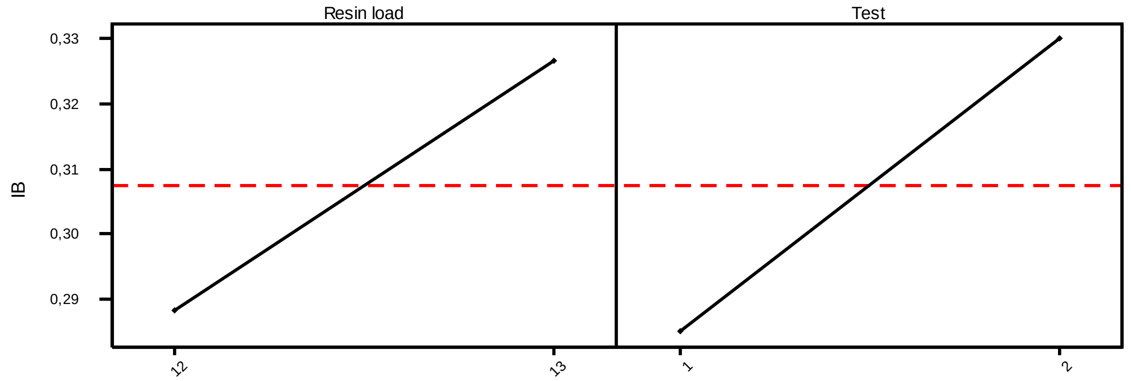
```
Analysis of Variance for IB, using Adjusted SS for Tests

Source            DF     Seq SS     Adj SS     Adj MS        F      P
Resin load         1   0,008817   0,008817   0,008817     2,22  0,152
Test               1   0,012150   0,012150   0,012150     3,06  0,096
Resin load*Test    1   0,002817   0,002817   0,002817     0,71  0,410
Error             20   0,079467   0,079467   0,003973
Total             23   0,103250
```

Neither the resin loading nor the test number is significant at 95% confidence interval for the IB of the panels produced at 475kg/m^3 density, and there is no interaction between them.

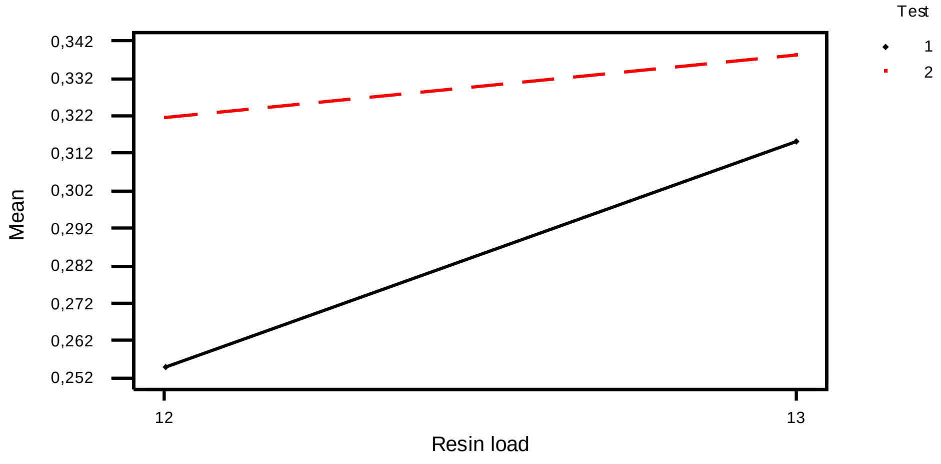
Internal plot for Mean IB at 95% confidence interval



Main Effects Plot - Data Means for IB



Interaction Plot - Data Means for IB

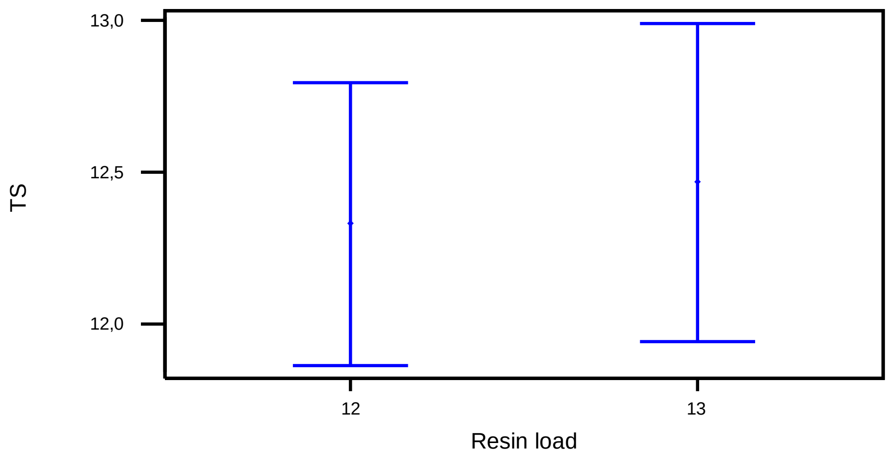


Analysis of Variance for TS, using Adjusted SS for Tests

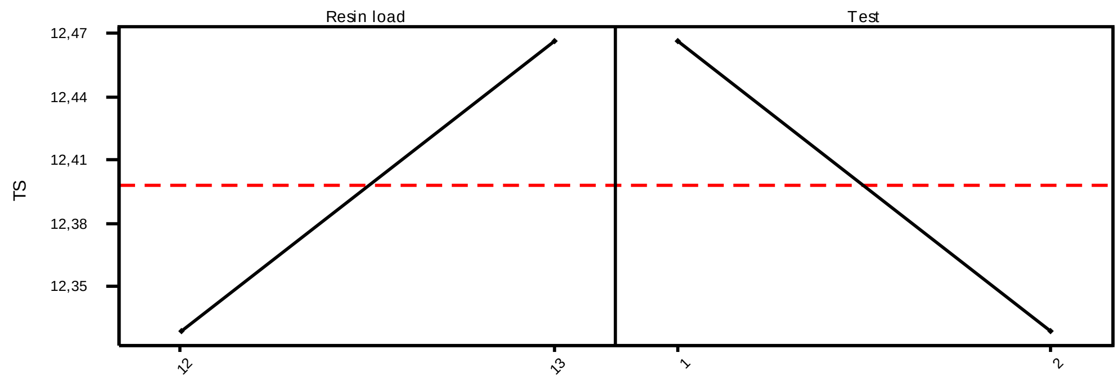
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Resin load	1	0,1134	0,1134	0,1134	0,18	0,673
Test	1	0,1134	0,1134	0,1134	0,18	0,673
Resin load*Test	1	0,8550	0,8550	0,8550	1,38	0,253
Error	20	12,3625	12,3625	0,6181		
Total	23	13,4444				

None of the factors examined is significant at 95% confidence interval for the swelling of the LSB produced.

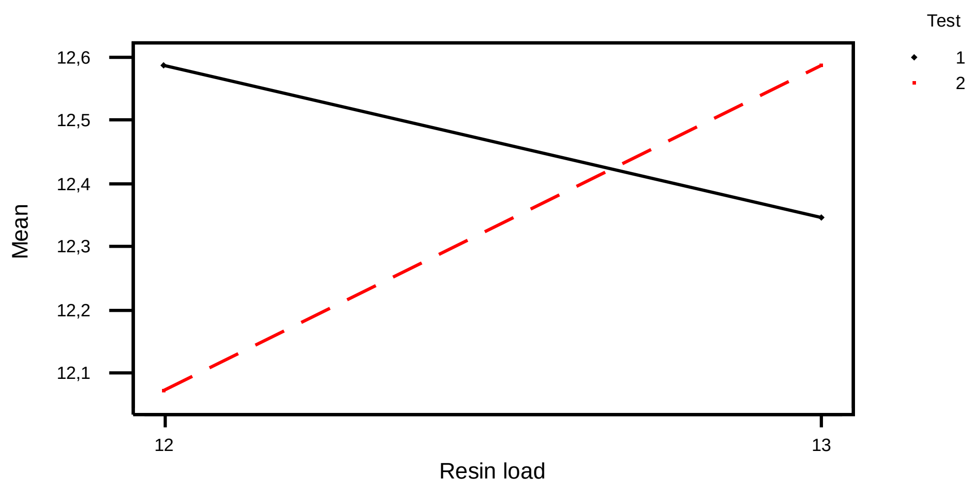
Internal plot for Mean TS at 95% confidence interval



Main Effects Plot - Data Means for TS



Interaction Plot - Data Means for TS

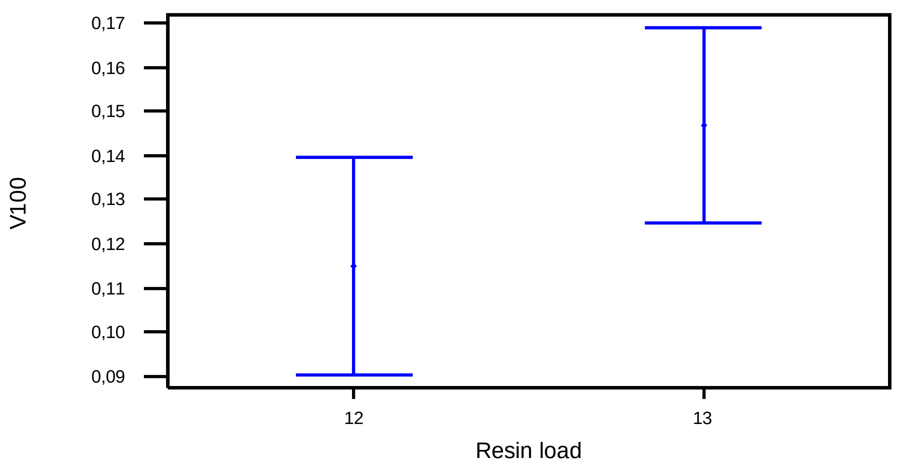


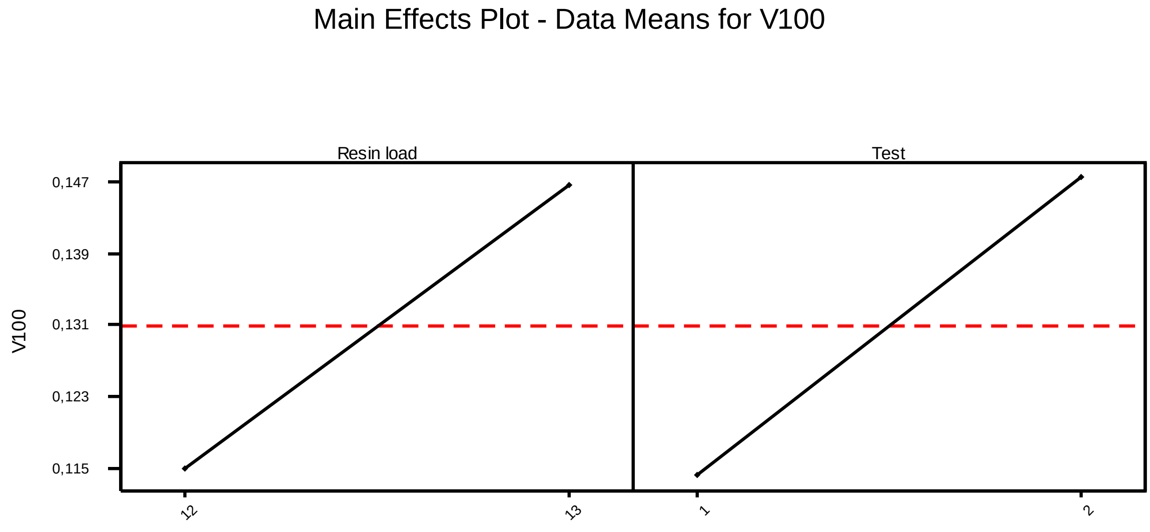
Analysis of Variance for V100, using Adjusted SS for Tests

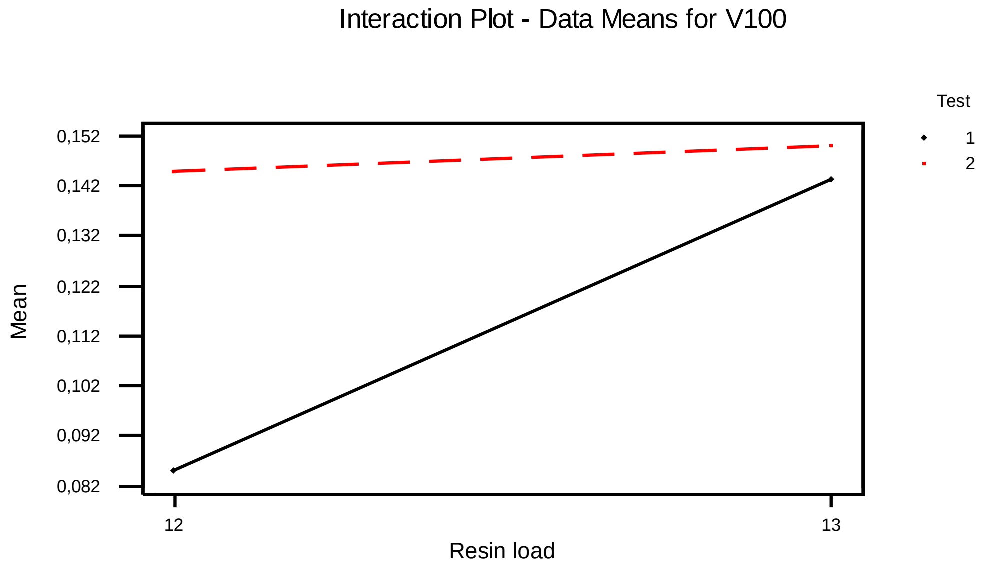
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Resin load	1	0,0060167	0,0060167	0,0060167	6,46	**0,019**
Test	1	0,0066667	0,0066667	0,0066667	7,16	**0,015**
Resin load*Test	1	0,0042667	0,0042667	0,0042667	4,58	**0,045**
Error	20	0,0186333	0,0186333	0,0009317		
Total	23	0,0355833				

For the V100 of LSB both the resin loading and the test number **are significant** at 95% confidence interval (P<0.050) and there is interaction between them.

Internal plot for Mean V100 at 95% confidence interval



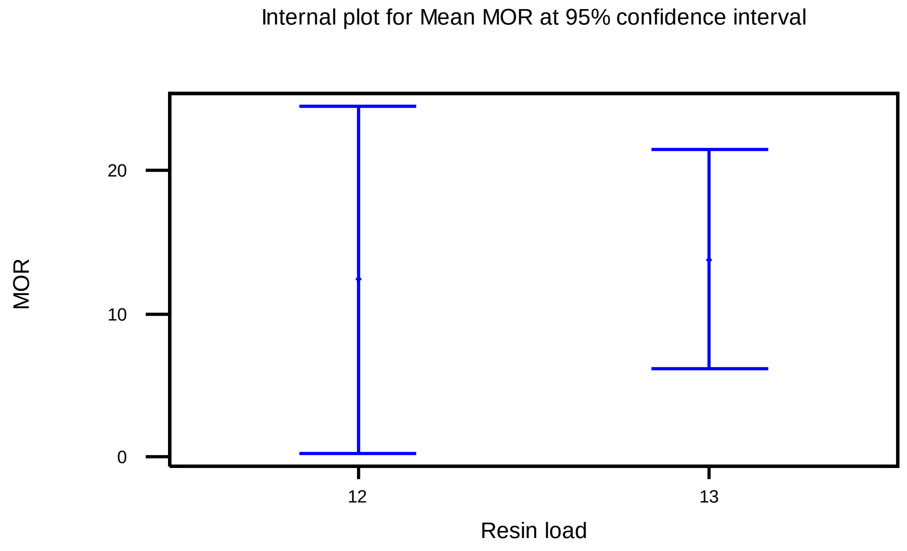


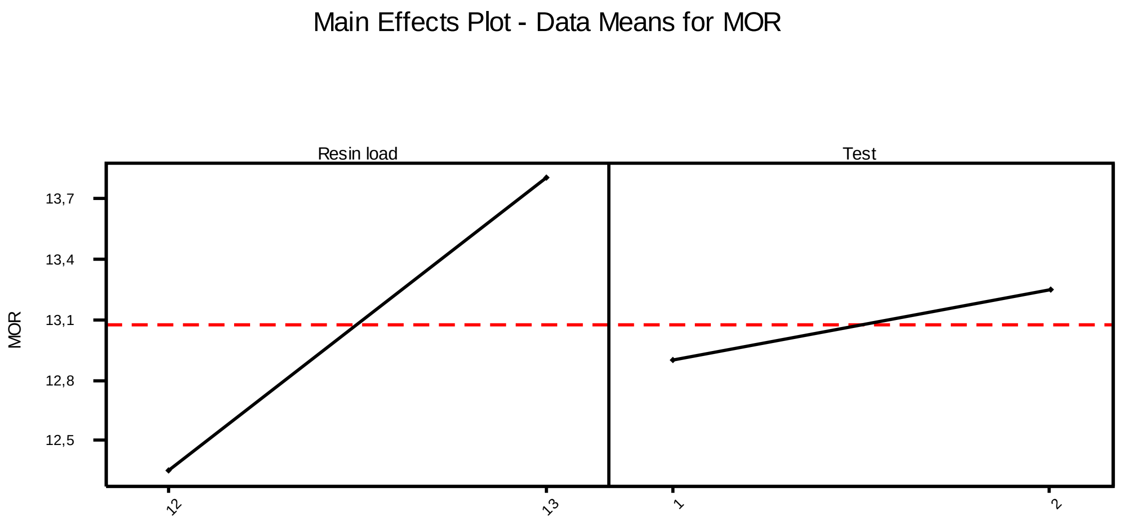


Analysis of Variance for MOR, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Resin load	1	2,102	2,102	2,102	0,88	0,521
Test	1	0,122	0,122	0,122	0,05	0,859
Error	1	2,403	2,403	2,403		
Total	3	4,627				

None of the factors is significant for the MOR of the light weight OSB panels.

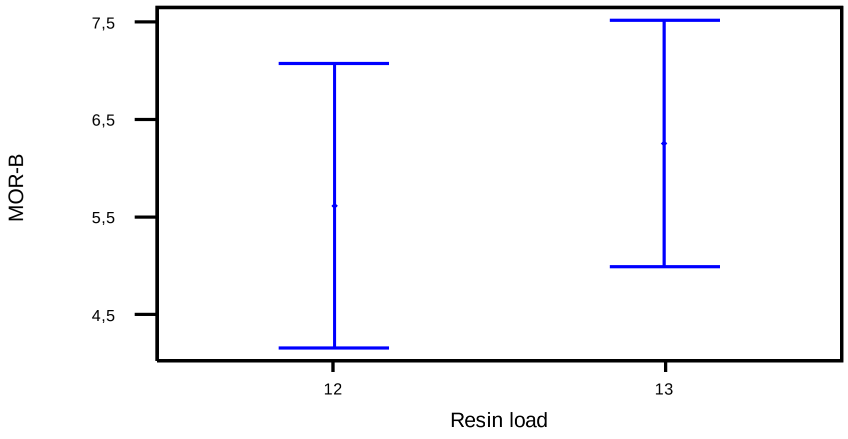




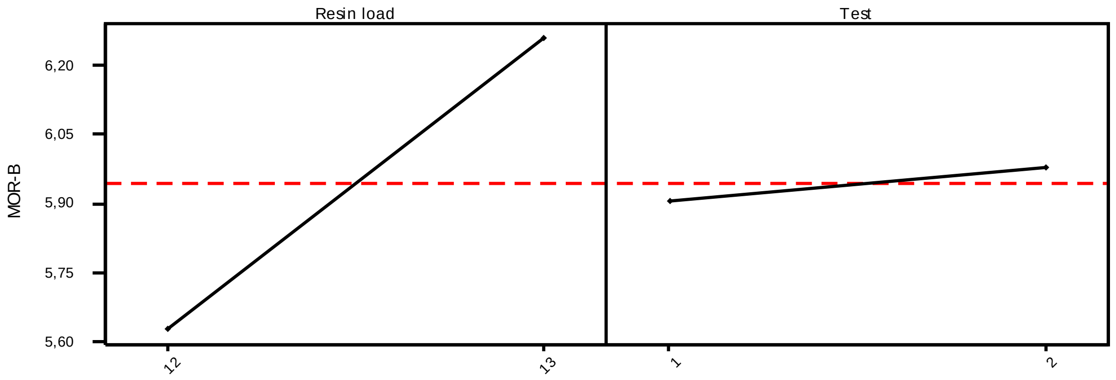

```
Analysis of Variance for MOR-B, using Adjusted SS for Tests

Source            DF     Seq SS     Adj SS     Adj MS       F      P
Resin load         1     0,8065     0,8065     0,8065    1,04  0,365
Test               1     0,0112     0,0112     0,0112    0,01  0,910
Resin load*Test    1     1,2960     1,2960     1,2960    1,68  0,265
Error              4     3,0930     3,0930     0,7732
Total              7     5,2067
```

Neither the resin loading nor the test number is significant at 95% confidence interval for the MOR-B of the panels.

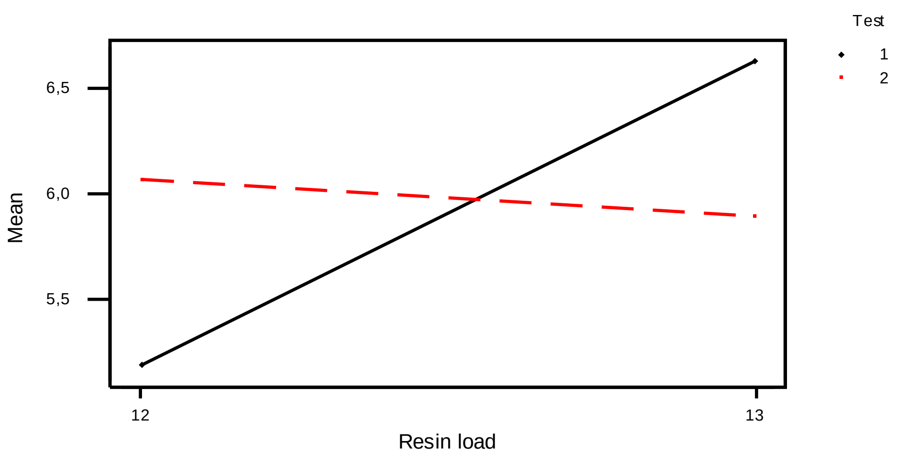
Internal plot for Mean MOR-B at 95% confidence interval



Main Effects Plot - Data Means for MOR-B



Interaction Plot - Data Means for MOR-B

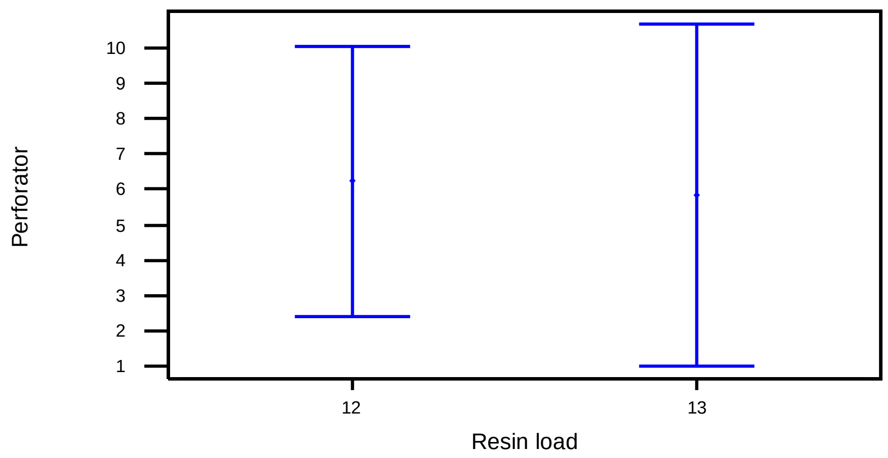


Analysis of Variance for Perforator, using Adjusted SS for Tests

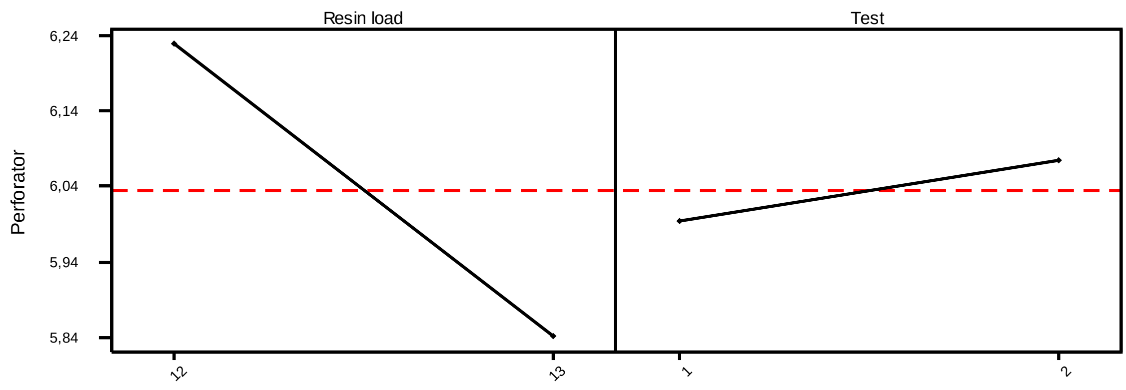
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Resin load	1	0,1521	0,1521	0,1521	0,33	0,668
Test	1	0,0064	0,0064	0,0064	0,01	0,925
Error	1	0,4624	0,4624	0,4624		
Total	3	0,6209				

For the formaldehyde content of the OSB panels none of the factors examined is significant at 95% confidence interval.

Internal plot for Mean Perforator at 95% confidence interval



Main Effects Plot - Data Means for Perforator



The panel testing results and the analysis of variance show that the increased resin factor improves the properties of the LSB panels produced in the lab. However, the property values in some cases are on the borderline of the standard requirements, and therefore it is worth testing a higher resin loading so as to ensure satisfactory results.

For the production of LSB with density of 450kg/m^3, three resin loading levels were applied, namely 12, 14 and 16% w/w dry resin on dry wood, since the properties decrease was more pronounced in this density range. The same binder system was applied in this case too and the production settings are summarized in the next table.

Table 10: *OSB production details*

Board Dimensions, cm	43 x 43 x 1.6
Target Density, kg/m^3	450
Target board moisture, %	6.5
Press Factor, s/mm	12
Press Temperature, ^{o}C	180
Wood Source	IBL/IMAL
Resin Factor, % solid on dry wood	12, 14 and 16
Paraffin Level, % solid on dry wood	1.0
Hardener Type and Level, % solid on solid resin	HR-2, 3.5
Crosslinker Type and Level, % dry on liquid resin	CR-1, 9.0
Target mat moisture, %	10.5
Strands initial target moisture, %	3.5

The panels obtained were subjected to the full range of tests – IB, TS, V100, MOR, MOR-B and perforator test. The average testing values are summarized in the next table.

Table 11: *OSB Testing results*

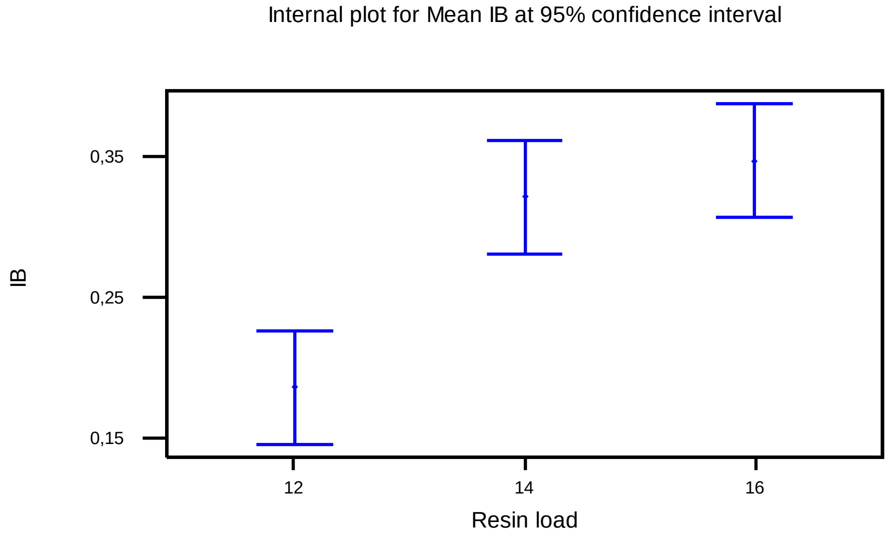
Press temperature, ^{o}C	180		
Press cycle, s/mm	12		
Hardener HR-2 level, %	3.5		
Crosslinker CR-1 level, %	9.0		
Target density, kg/m^3	450		
Resin Factor, % dry on dry wood	12	14	16
Thickness, mm	16.12	16.08	16.03
Density, kg/m^3	444	451	455
IB, MPa	0.18	0.32	0.35
V100, MPa	0.08	0.13	0.15
TS, %	12.52	13.33	11.93
MOR, MPa	14.33	14.85	16.22
MOR-B, MPa	4.38	4.93	6.14
Perforator, mg/100g	6.21	6.00	6.61

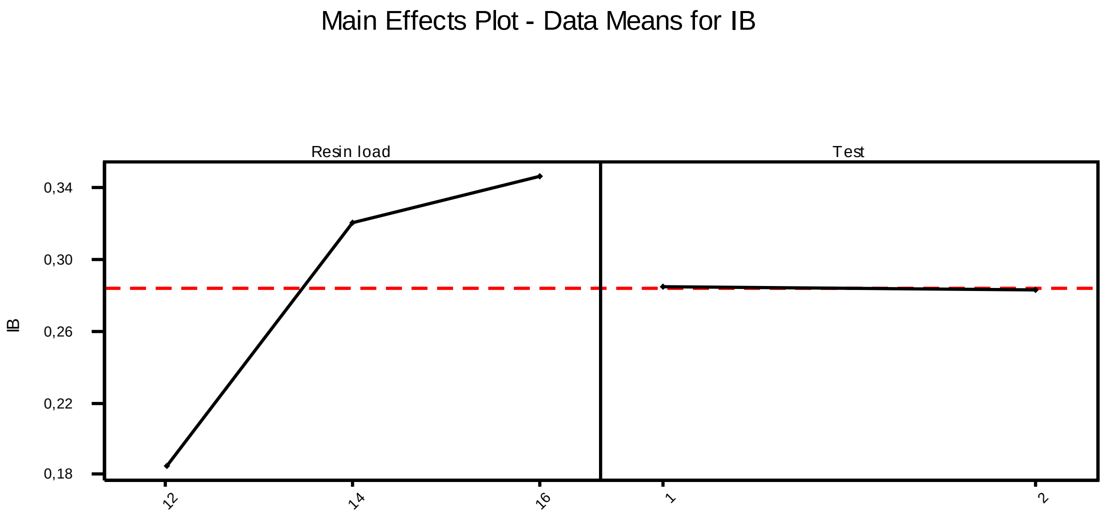
The ANOVA results obtained are the following:

Analysis of Variance for IB, using Adjusted SS for Tests

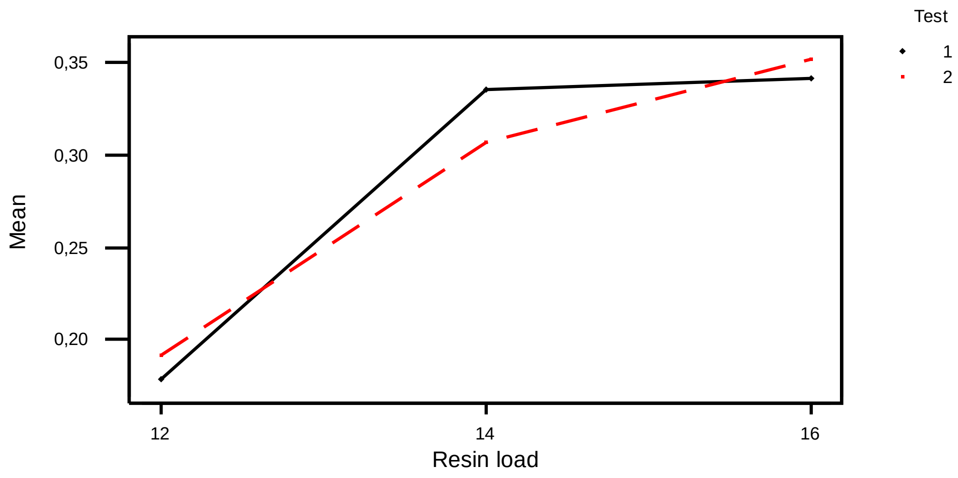
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Resin load	2	0,181017	0,181017	0,090508	20,82	**0,000**
Test	1	0,000025	0,000025	0,000025	0,01	0,940
Resin load*Test	2	0,003217	0,003217	0,001608	0,37	0,694
Error	30	0,130417	0,130417	0,004347		
Total	35	0,314675				

Only the resin loading is significant factor at 95% confidence interval (P<0.050) for the IB of the panels and there is no interaction with the test number.





Interaction Plot - Data Means for IB

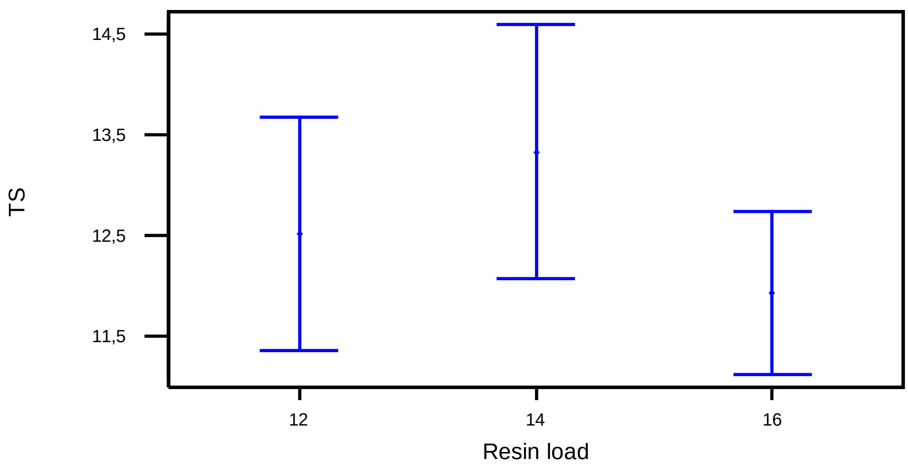


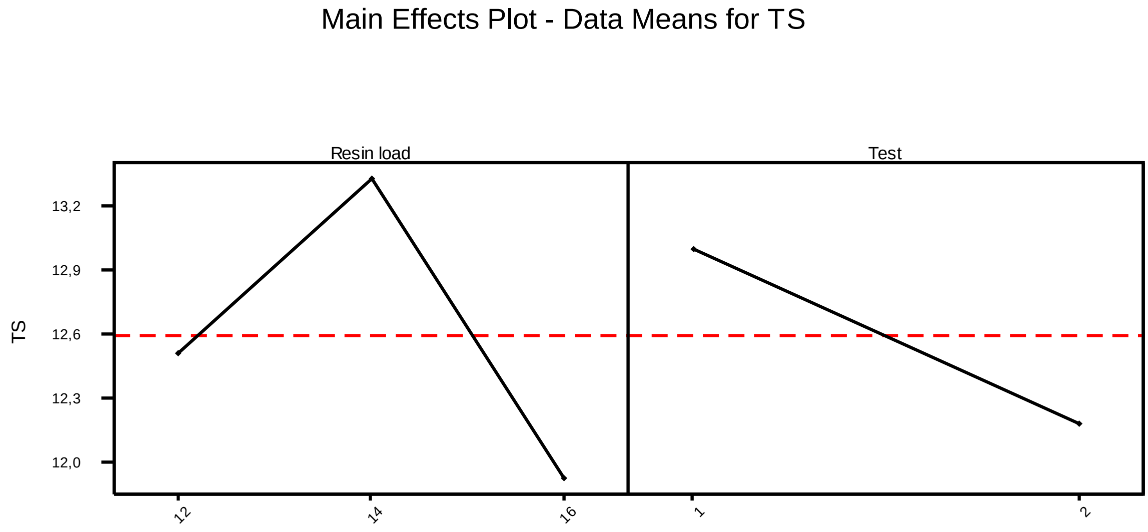
Analysis of Variance for TS, using Adjusted SS for Tests

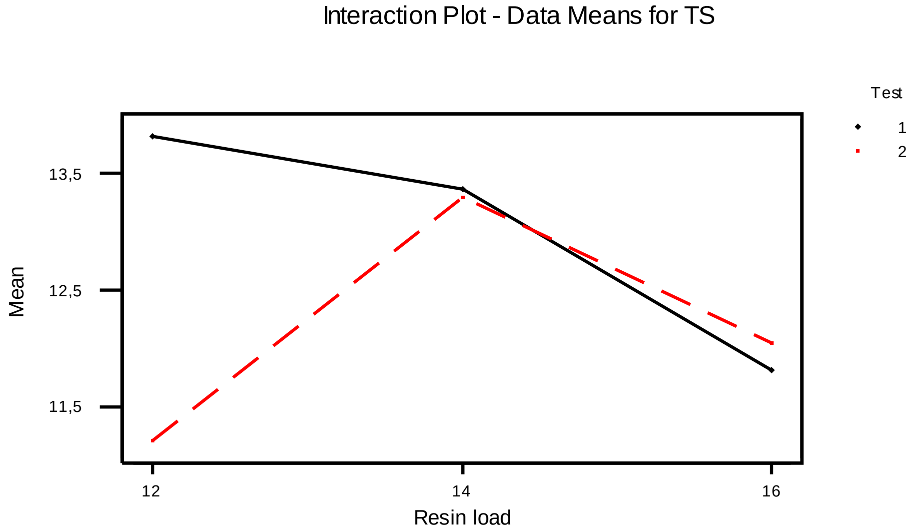
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Resin load	2	11,988	11,988	5,994	2,30	0,117
Test	1	6,035	6,035	6,035	2,32	0,138
Resin load*Test	2	14,991	14,991	7,496	2,88	0,072
Error	30	78,126	78,126	2,604		
Total	35	111,141				

None of the factors examined **is significant** for the swelling of LSB at 95% confidence interval.

Internal plot for Mean TS at 95% confidence interval







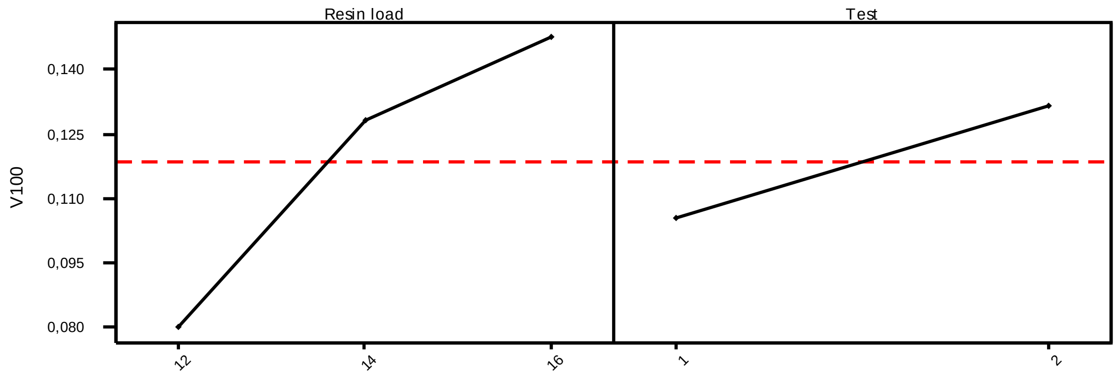
Analysis of Variance for V100, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Resin load	2	0,029039	0,029039	0,014519	11,96	**0,000**
Test	1	0,006136	0,006136	0,006136	5,05	**0,032**
Resin load*Test	2	0,000039	0,000039	0,000019	0,02	0,984
Error	30	0,036417	0,036417	0,001214		
Total	35	0,071631				

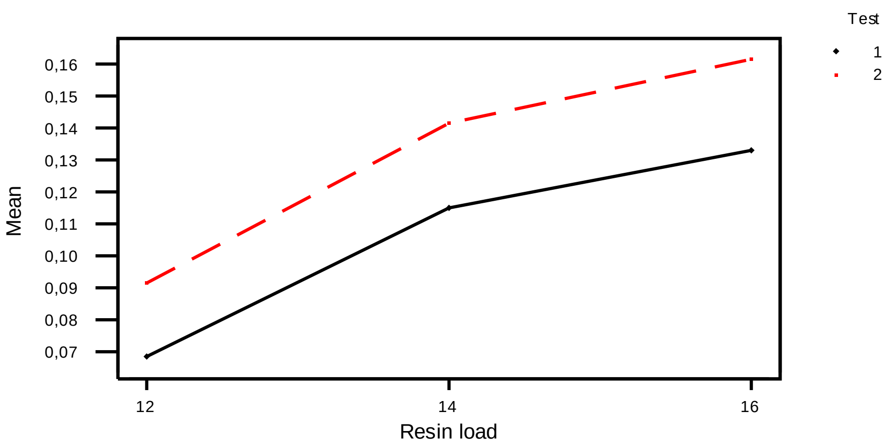
Both the resin loading and the number of test **are significant** factors at 95% confidence interval (P<0.050) for the V100 of the panels produced at 450kg/m^3 density.

Internal plot for Mean V100 at 95% confidence interval

Main Effects Plot - Data Means for V100



Interaction Plot - Data Means for V100

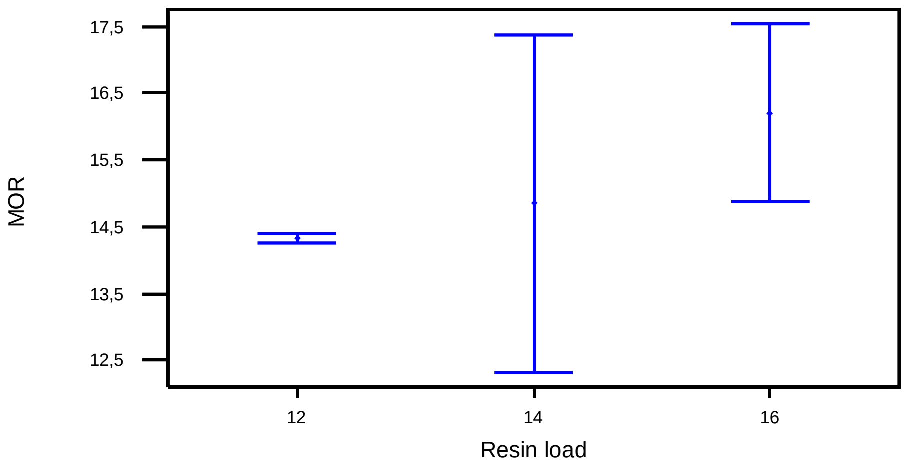


Analysis of Variance for MOR, using Adjusted SS for Tests

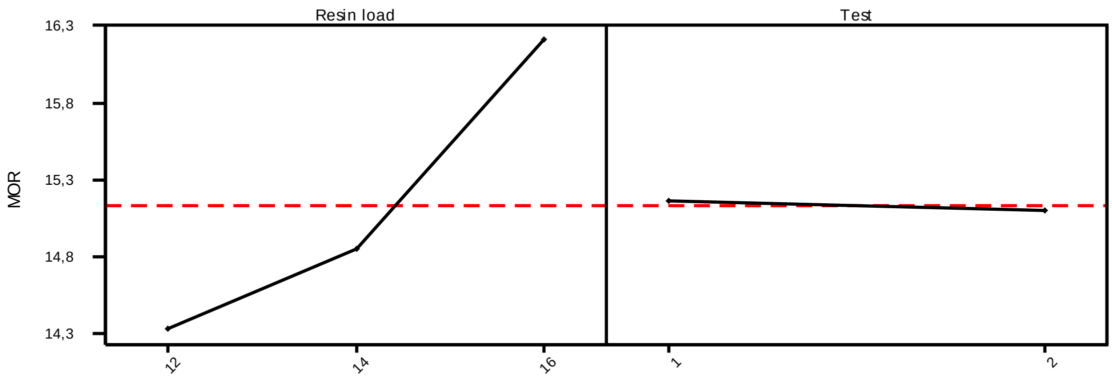
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Resin load	2	3,8073	3,8073	1,9037	39,37	**0,025**
Test	1	0,0054	0,0054	0,0054	0,11	0,770
Error	2	0,0967	0,0967	0,0484		
Total	5	3,9094				

Only the resin loading **is significant** at 95% confidence interval (P<0.050) for MOR of the panels.

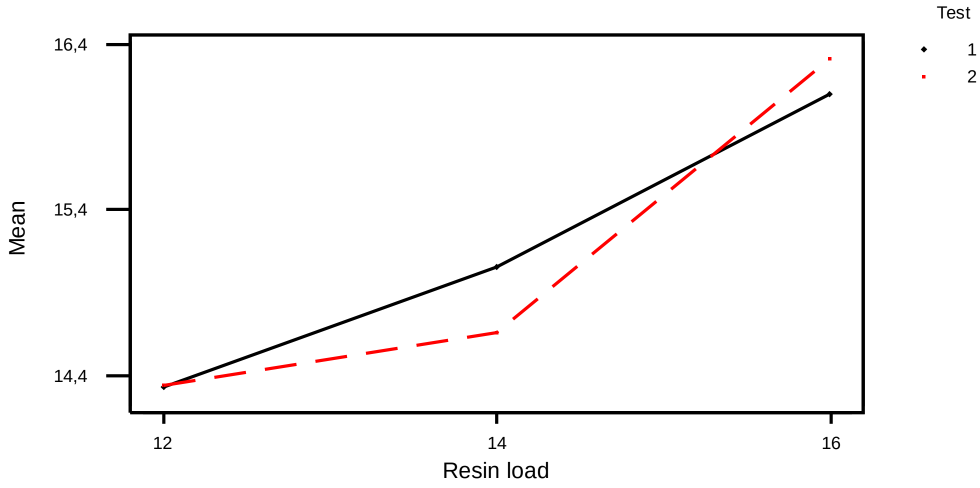
Internal plot for Mean MOR at 95% confidence interval



Main Effects Plot - Data Means for MOR



Interaction Plot - Data Means for MOR

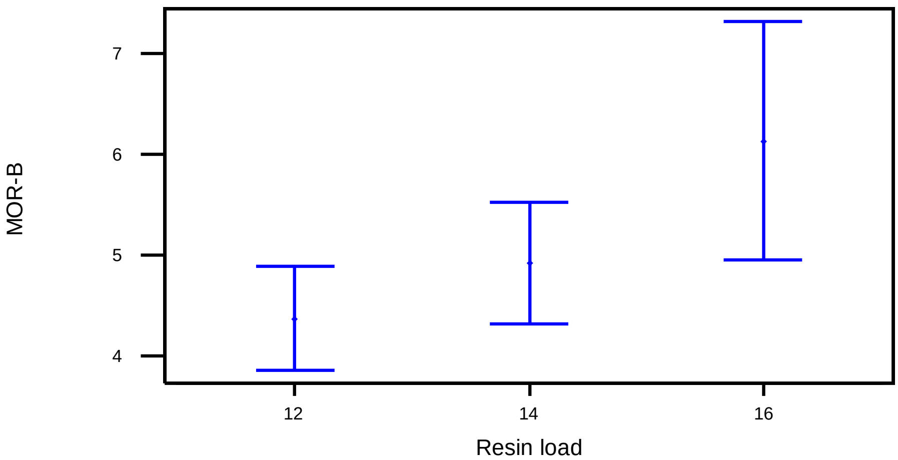


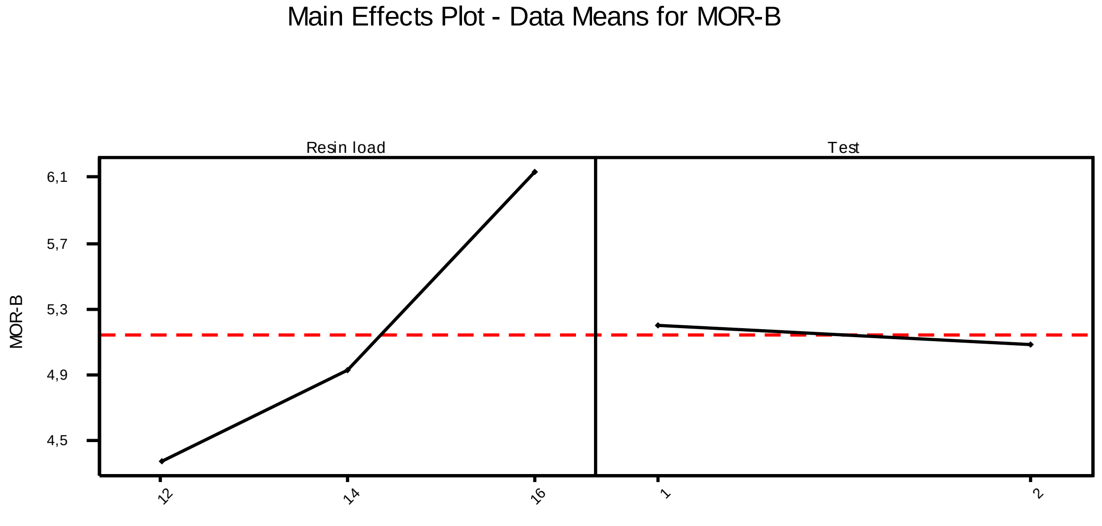
Analysis of Variance for MOR-B, using Adjusted SS for Tests

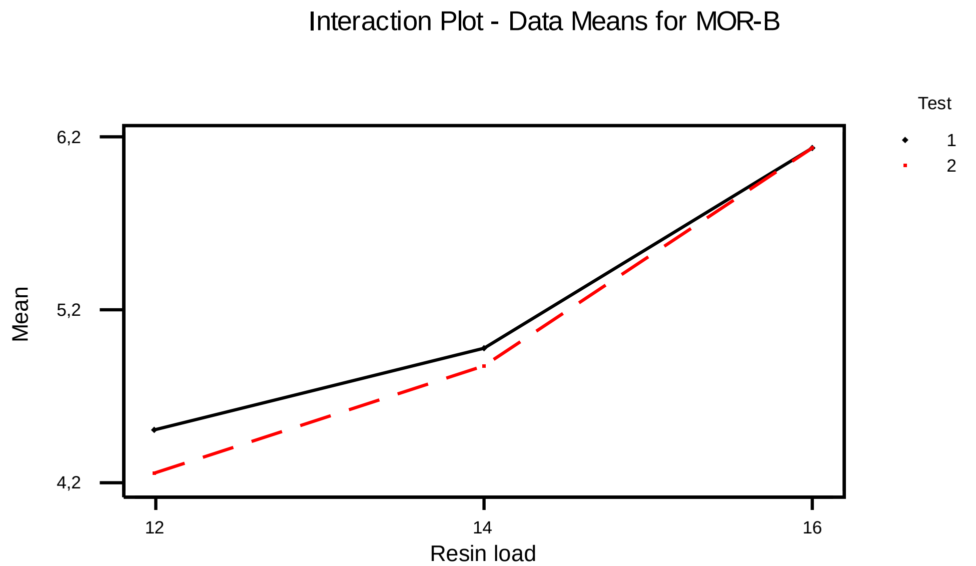
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Resin load	2	6,4856	6,4856	3,2428	8,30	**0,019**
Test	1	0,0408	0,0408	0,0408	0,10	0,757
Resin load*Test	2	0,0317	0,0317	0,0158	0,04	0,961
Error	6	2,3432	2,3432	0,3905		
Total	11	8,9013				

Also for MOR-B only the resin loading **is significant** factor at 95% confidence interval (P<0.050).

Internal plot for Mean MOR-B at 95% confidence interval





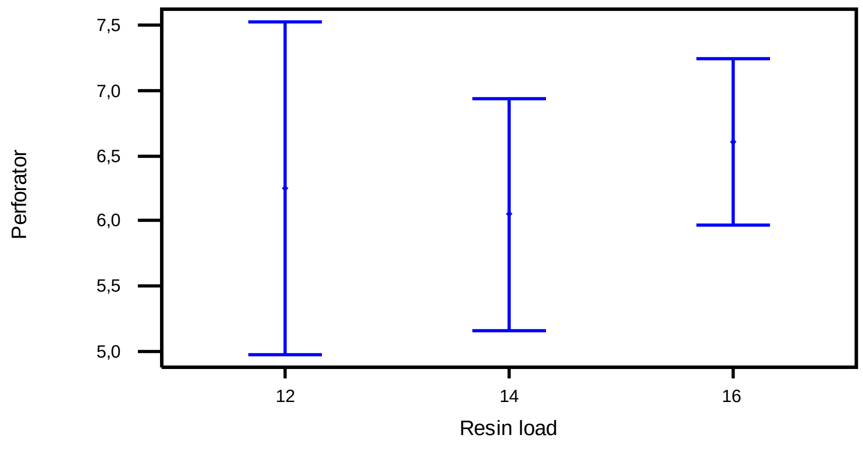


Analysis of Variance for Perforat, using Adjusted SS for Tests

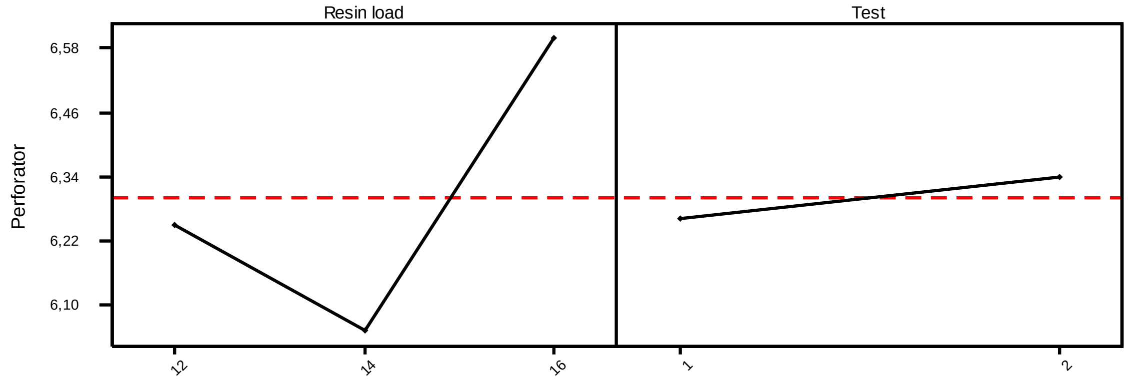
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Resin load	2	0,31000	0,31000	0,15500	12,30	0,075
Test	1	0,00960	0,00960	0,00960	0,76	0,475
Error	2	0,02520	0,02520	0,01260		
Total	5	0,34480				

None of the factors is significant for the formaldehyde content of the LSB produced.

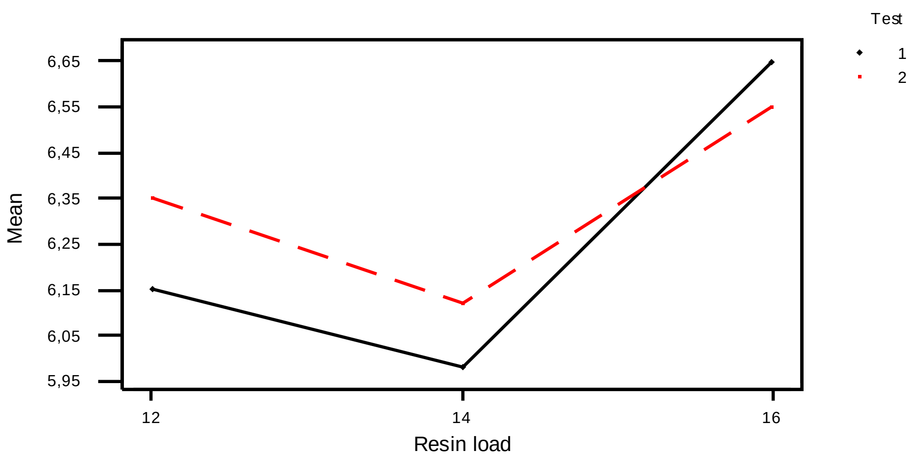
Internal plot for Mean Perforator at 95% confidence interval



Main Effects Plot - Data Means for Perforator



Interaction Plot - Data Means for Perforator



The above results indicate that the higher the resin factor, the better the properties of the LSB produced in the lab. Despite the fact that most of the properties of the panels with 14% resin factor meet the standard requirements, they are, however, on the borderline, and therefore it seems that the 16% resin loading is more appropriate for the density of 450kg/m^3.

In the meantime, a new batch of poplar strands of I-214 clone was delivered at CHIMAR (April 2014) to continue with the research work. The pH and buffer capacity of the stands were found to be 6.37 and 5.95 ml 0.1N HCl respectively (Figure 1).

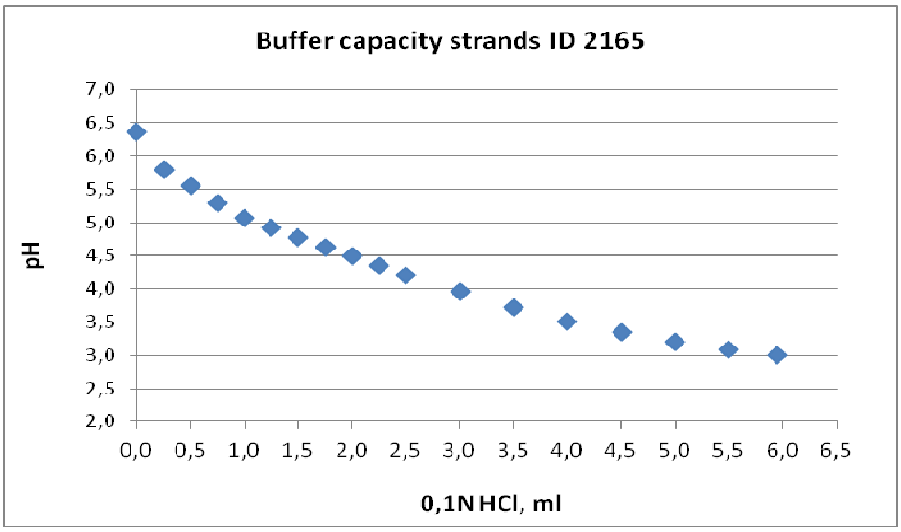


Figure 1. *Buffer capacity of poplar strands delivered at CHIMAR in April 2014.*

The new strands were used to press LSB with three different density values, 500, 475 and 450 kg/m^3 with resin loading levels of 12, 14 and 16% w/w dry resin on dry wood respectively, so as to verify the results previously found. The MUPF resin used for this trial had the following properties:

Table 12: *Resin properties*

Resin type	MUPF
Viscosity, 25°C, cP	225
pH, 25°C,	9.55
Water Tolerance, 25°C, ml/ml	1: 0.50
Solids, 2g 2h 120°C, %	64.35
Gel time, 3.5% $(NH_4)_2SO_4$, s	72

The production details and settings of the one layer strand boards with random orientation are shown in the next table.

Table 13: *OSB production details*

Board Dimensions, cm	43 x 43 x 1.6		
Target board moisture, %	6.5		
Press Factor, s/mm	12		
Press Temperature, °C	180		
Wood Source	IBL/IMAL		
Target Density, kg/m^3	500	475	450
Resin Factor, % solid on dry wood	12	14	16
Paraffin Level, % solid on dry wood	1.0		
Hardener Type and Level, % solid on solid resin	HR-2, 3.5		
Crosslinker Type and Level, % dry on liquid resin	CR-1, 9.0		
Target mat moisture, %	10.5		
Strands initial target moisture, %	3.5		

The panels obtained were subjected to the full range of tests – IB, TS, V100, MOR, MOR-B and perforator test. The average testing values are summarized in the next table.

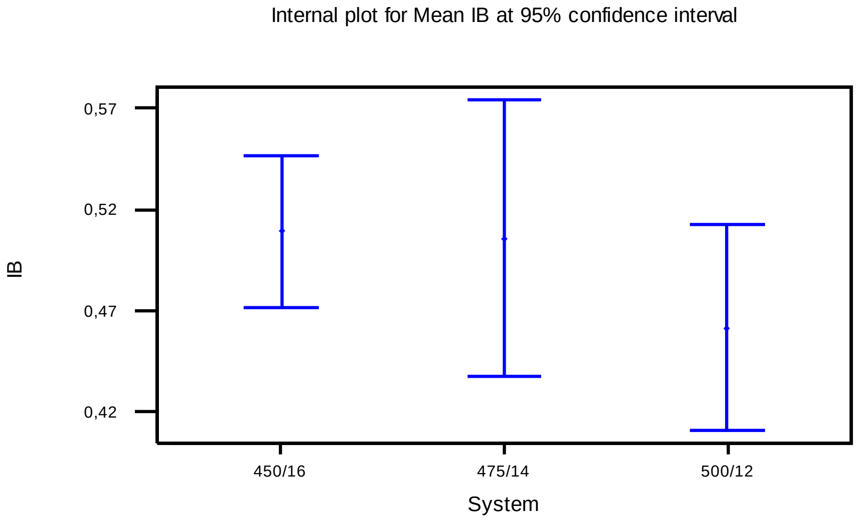
Table 14: *OSB Testing results*

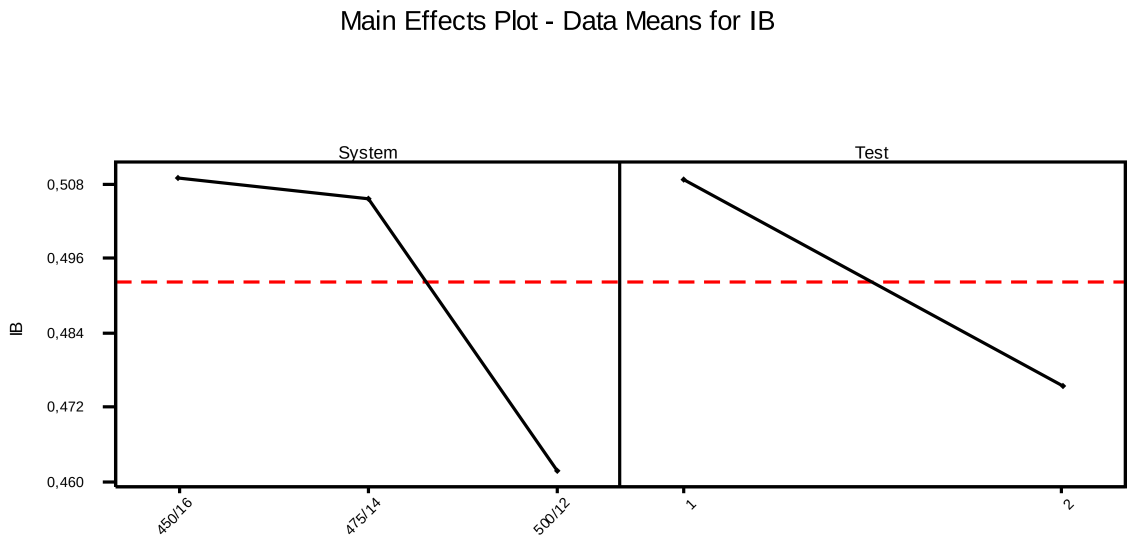
Press temperature, °C	180		
Press cycle, s/mm	12		
Hardener HR-2 level, %	3.5		
Crosslinker CR-1 level, %	9.0		
System: Density/Resin factor	500/12	475/14	450/16
Thickness, mm	16.18	16.06	16.06
Density, kg/m^3	494	472	444
IB, MPa	0.46	0.51	0.51
V100, MPa	0.17	0.19	0.23
TS, %	13.78	11.85	9.40
MOR, MPa	20.18	15.50	13.30
MOR-B, MPa	8.52	7.63	6.56
Perforator, mg/100g	4.98	4.67	4.69

The ANOVA results obtained are the following:

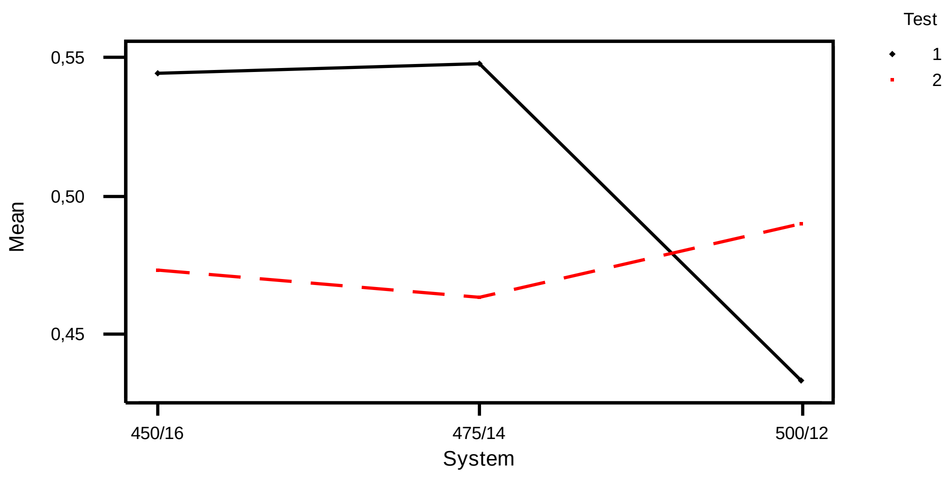
```
Analysis of Variance for IB, using Adjusted SS for Tests

Source         DF     Seq SS     Adj SS     Adj MS       F      P
System          2   0,016872   0,016872   0,008436    1,34  0,277
Test            1   0,010000   0,010000   0,010000    1,59  0,217
System*Test     2   0,036717   0,036717   0,018358    2,91  0,070
Error          30   0,189033   0,189033   0,006301
Total          35   0,252622
```

Neither the system nor the test number is significant factor for the IB at 95% confidence interval and there is no interaction between them.





Interaction Plot - Data Means for IB

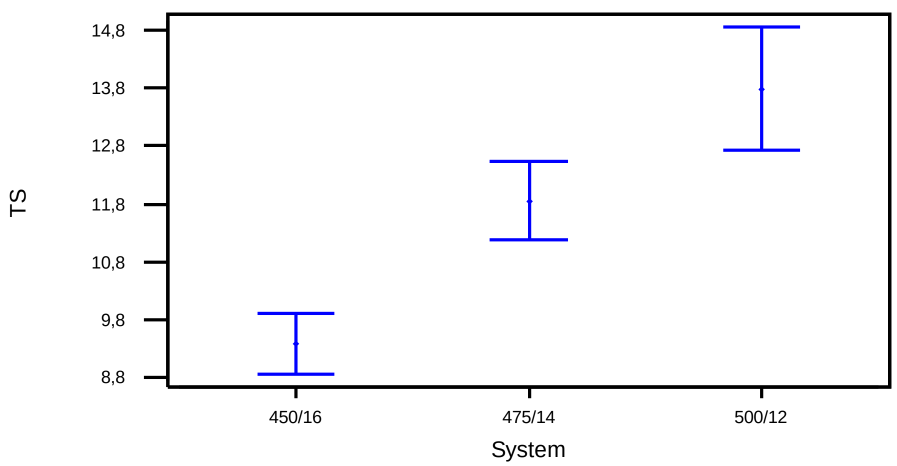


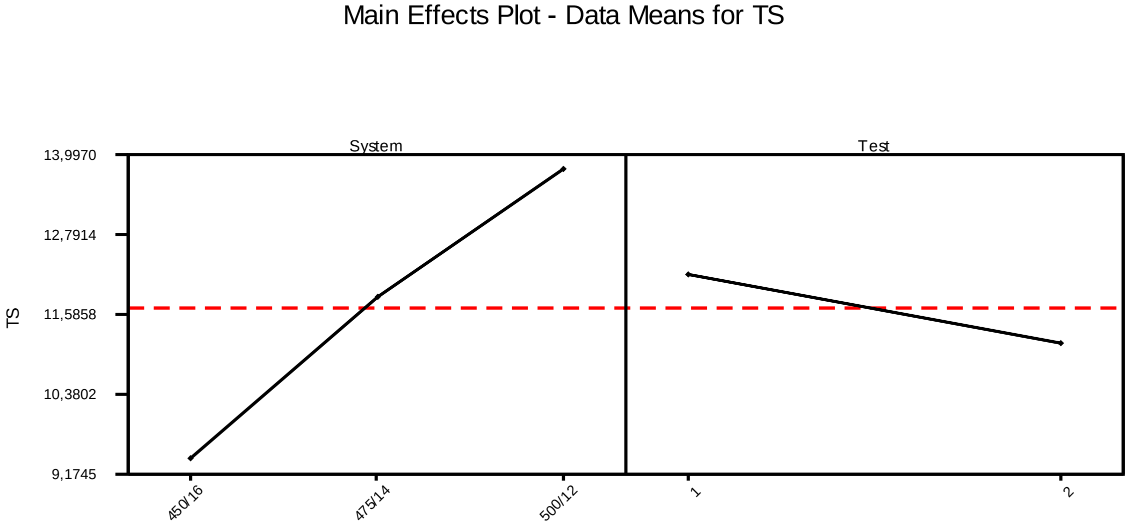
Analysis of Variance for TS, using Adjusted SS for Tests

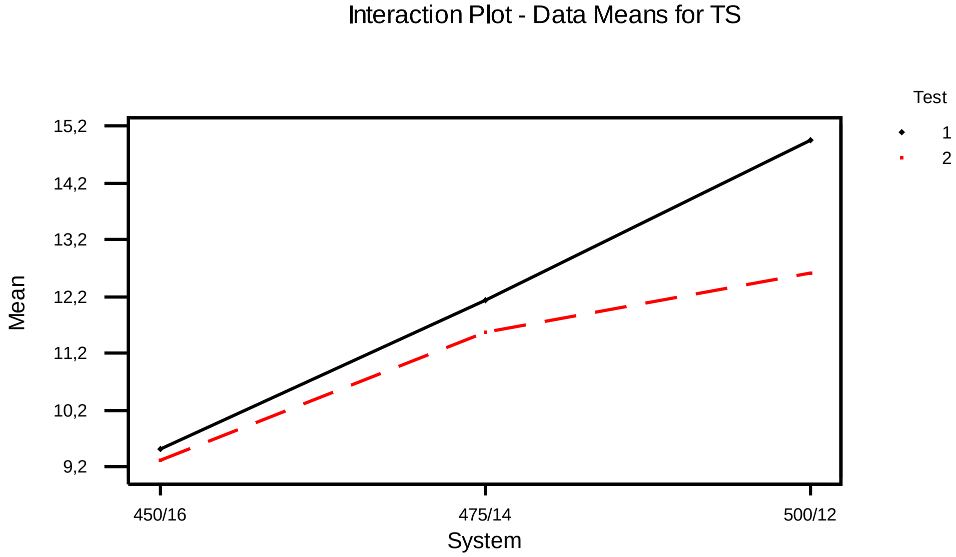
Source	DF	Seq SS	Adj SS	Adj MS	F	P
System	2	115,336	115,336	57,668	53,13	**0,000**
Test	1	9,724	9,724	9,724	8,96	**0,005**
System*Test	2	7,922	7,922	3,961	3,65	**0,038**
Error	30	32,564	32,564	1,085		
Total	35	165,545				

Both factors examined, system and test number, **are significant** at 95% confidence interval (P<0.050) for the swelling of the LSB produced in the lab, and there is interaction between them.

Internal plot for Mean TS at 95% confidence interval





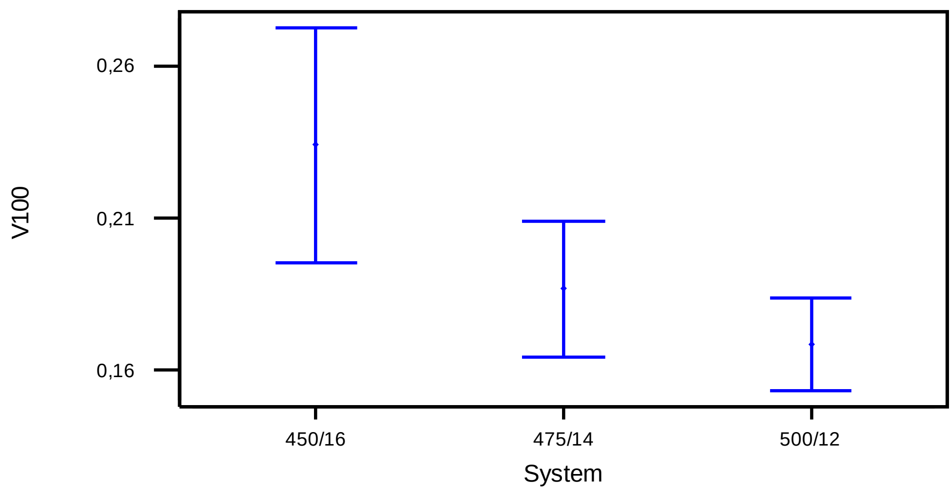


Analysis of Variance for V100, using Adjusted SS for Tests

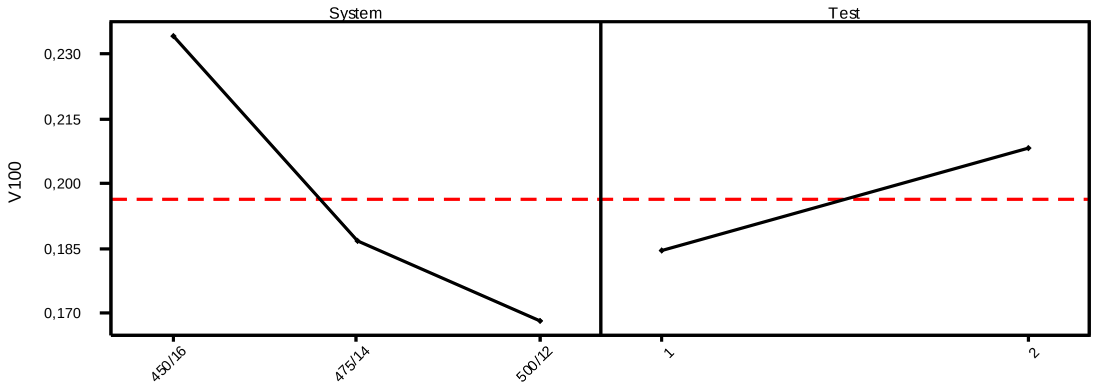
Source	DF	Seq SS	Adj SS	Adj MS	F	P
System	2	0,027706	0,027706	0,013853	7,70	**0,002**
Test	1	0,005136	0,005136	0,005136	2,86	0,101
System*Test	2	0,002239	0,002239	0,001119	0,62	0,543
Error	30	0,053950	0,053950	0,001798		
Total	35	0,089031				

Only the system is significant factor for the V100 of the panels at 95% confidence interval (P<0.050).

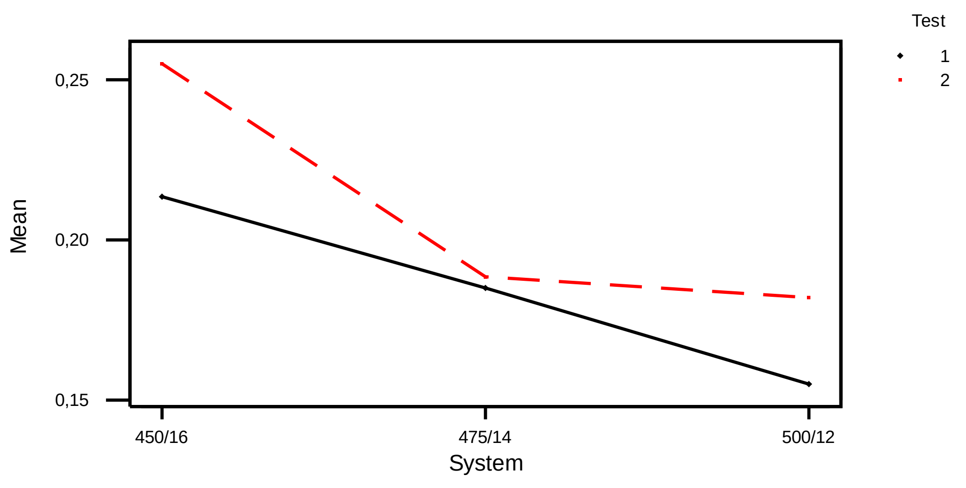
Internal plot for Mean V100 at 95% confidence interval



Main Effects Plot - Data Means for V100



Interaction Plot - Data Means for V100

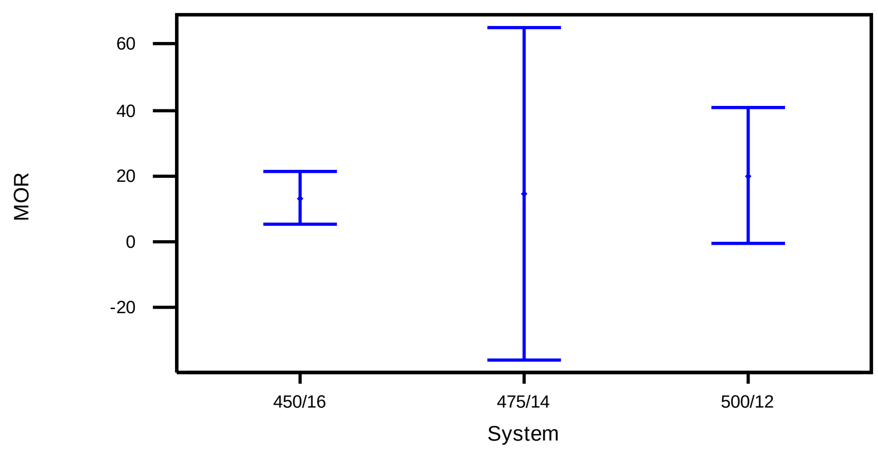


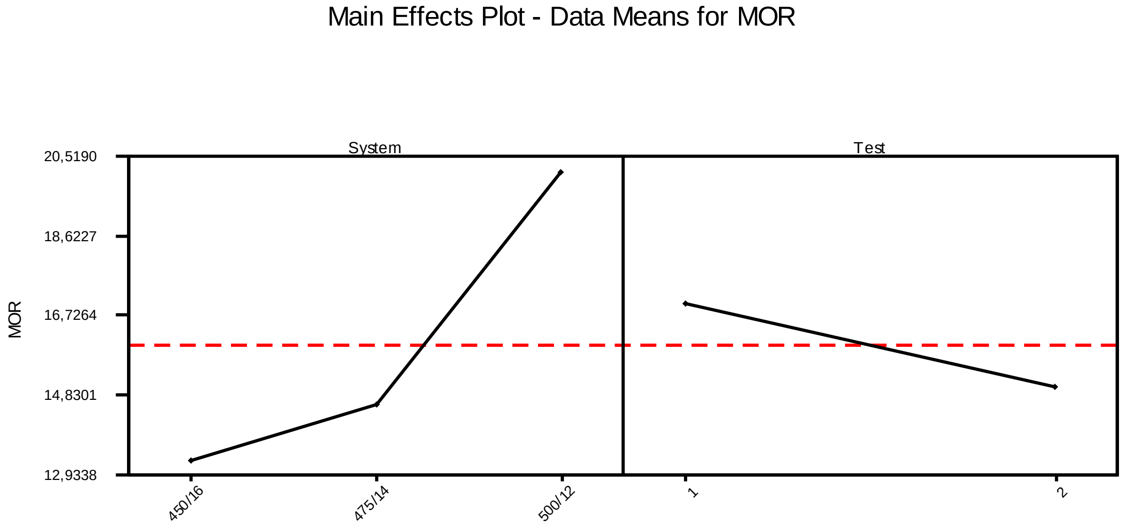
Analysis of Variance for MOR, using Adjusted SS for Tests

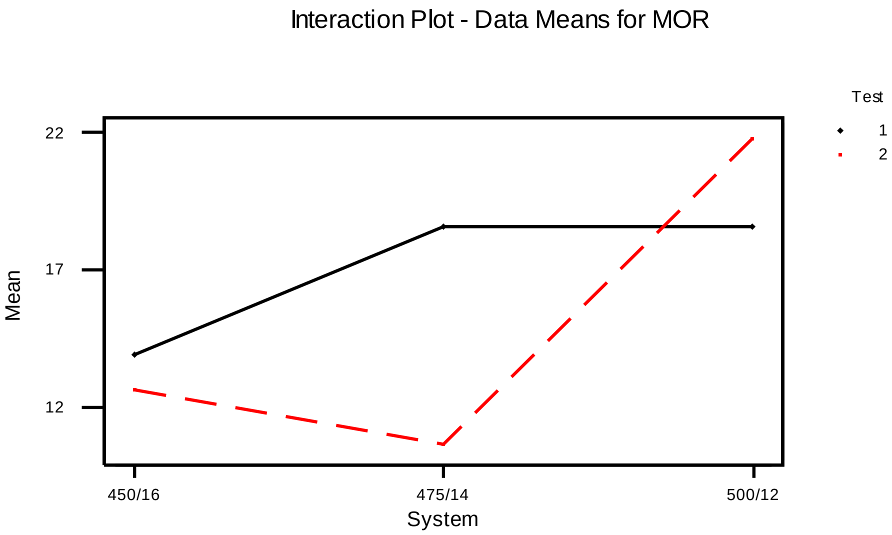
Source	DF	Seq SS	Adj SS	Adj MS	F	P
System	2	53,33	53,33	26,66	1,70	0,370
Test	1	5,94	5,94	5,94	0,38	0,601
Error	2	31,30	31,30	15,65		
Total	5	90,57				

None of the factors examined is significant at 95% confidence interval for the MOR of the LSB.

Internal plot for Mean MOR at 95% confidence interval





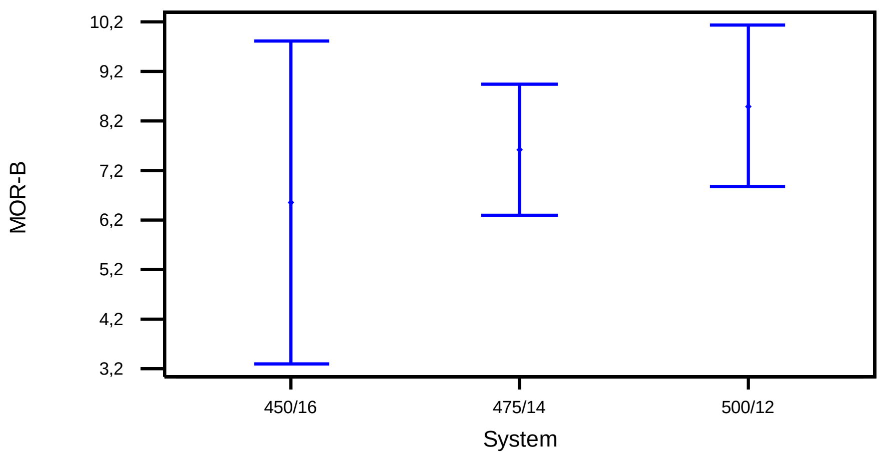


Analysis of Variance for MOR-B, using Adjusted SS for Tests

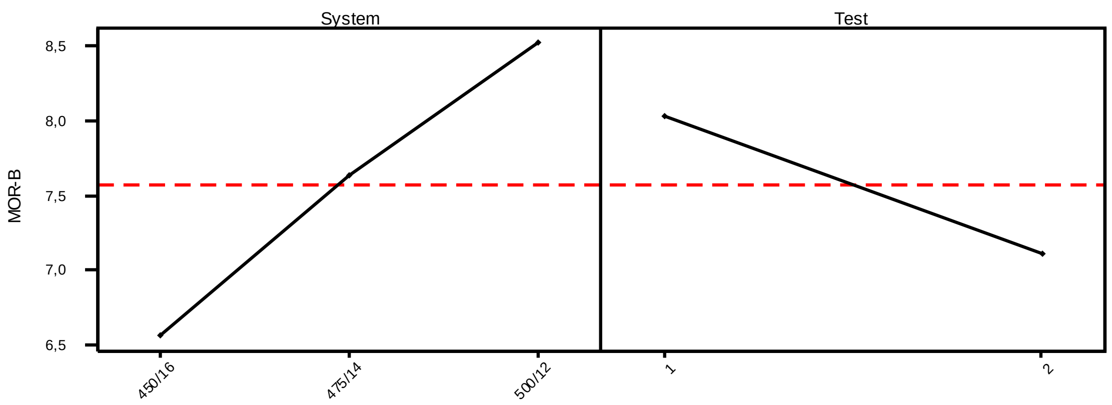
Source	DF	Seq SS	Adj SS	Adj MS	F	P
System	2	7,667	7,667	3,833	2,77	0,141
Test	1	2,493	2,493	2,493	1,80	0,228
System*Test	2	7,032	7,032	3,516	2,54	0,159
Error	6	8,316	8,316	1,386		
Total	11	25,508				

None of the factors examined is significant at 95% confidence interval for the MOR-B of the LSB panels.

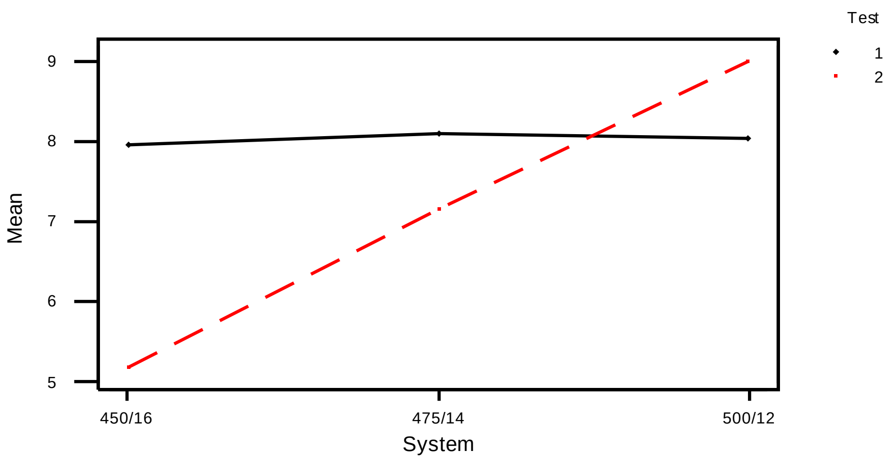
Internal plot for Mean MOR-B at 95% confidence interval



Main Effects Plot - Data Means for MOR-B



Interaction Plot - Data Means for MOR-B

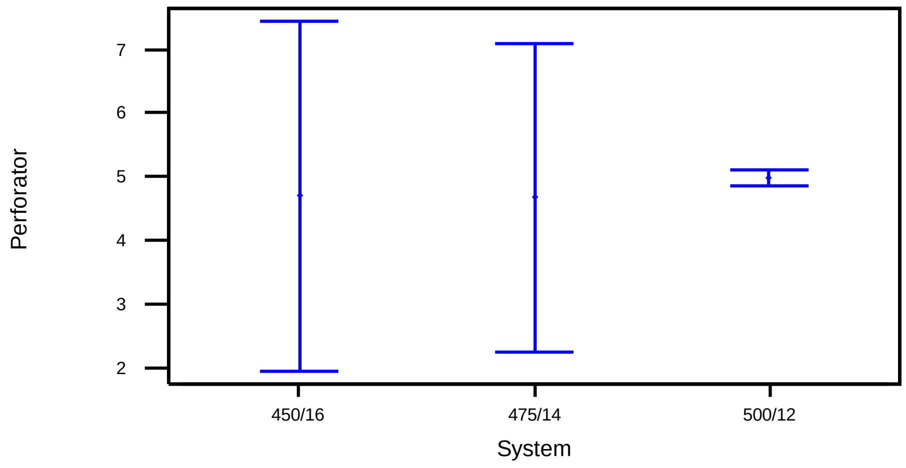


Analysis of Variance for Perforator, using Adjusted SS for Tests

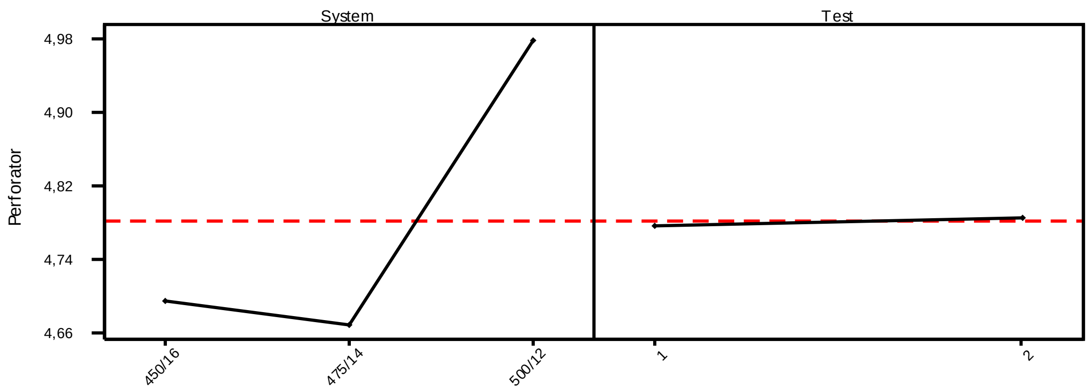
Source	DF	Seq SS	Adj SS	Adj MS	F	P
System	2	0,11863	0,11863	0,05932	0,72	0,581
Test	1	0,00015	0,00015	0,00015	0,00	0,970
Error	2	0,16470	0,16470	0,08235		
Total	5	0,28348				

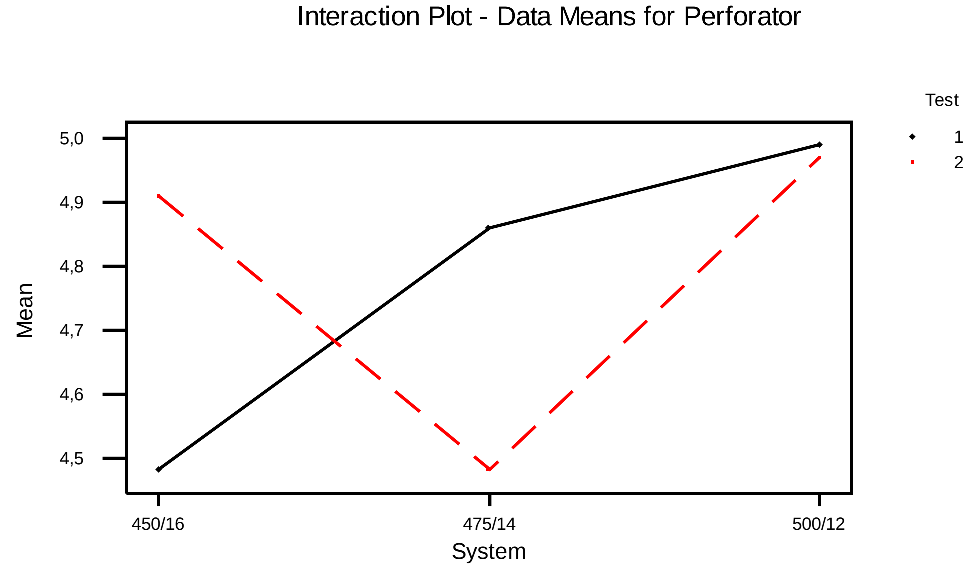
For the formaldehyde content of the LSB none of the factors examined are significant at 95% confidence interval.

Internal plot for Mean Perforator at 95% confidence interval



Main Effects Plot - Data Means for Perforator





The testing results indicate that for the panels with lower density, the increased resin loading can compensate the reduced property values to the extent that boards meeting the standard requirements can be obtained. There is statistically significant difference only in the swelling and V100, where the panels with lower density are superior, due to the increased resin factor. Both MOR and MOR-B values are decreased as the density of the lab panels is dropping. However, the values obtained are affected by that fact that the strands distribution is random rather than oriented. The formaldehyde content of all panels is well below the E1 standard limit. The fine tuning of the system can only be performed during an industrial trial, thus helping to identify the optimum resin factor for the reduced density of the OSB panels.

A further objective of this work was the application of PF type resin in the production of light weight OSB. Therefore, a PF resin with overall MR of 1.32, suitable for such an application, was synthesised in CHIMAR laboratory, tested and applied in the next panel production experiments. The properties of the resin are shown in the table below.

Table 15: *Resin properties*

Resin type	PF for OSB
Solids, 2g 2h 120°C, %	49.42
Viscosity, 25°C, cP	300
pH, 25°C	12.70
Free formaldehyde, %	0.34
Alkalinity, %	8.0
Gel time, 100°C, min	19

A common issue with the use of PF resin in particleboard (PB) or OSB production is its low reactivity, resulting in long press cycles. Therefore, further to a common type hardener like K_2CO_3, a special hardener developed by CHIMAR was used at two different levels (w/w dry on dry resin). The gel times at 100°C are depicted in the next table.

Table 16: *Gel times of PF with different hardeners*

Hardener type	K_2CO_3	H5545	H5545
Hardener level, dry/dry, %	2.5	3.0	5.0
Gel time 100°C, min:s	8:25	3:10	1:25

The press temperature and the press cycle used for the PF-LSB production were the same as those used in the case of MUPF resin system. The production details and settings of the one layer strand boards with random orientation are shown in the next table.

Table 17: *OSB production details*

Board Dimensions, cm	43 x 43 x 1.6	
Target Density, kg/m^3	500	
Target board moisture, %	6.5	
Press Factor, s/mm	12	
Press Temperature, °C	180	
Wood Source	IBL/IMAL	
Target Density, kg/m^3	500	
Resin Factor, % solid on dry wood	7.0	
Paraffin Level, % solid on dry wood	1.0	
Hardener Type and Level, % solid on solid resin	K_2CO_3, 2.5	H5545, 3.0 & 5.0
Target mat moisture, %	10.5	
Strands initial target moisture, %	3.5	

The panels obtained were subjected to IB, TS, V100, MOR, MOR-B and perforator tests. The average testing values are summarized in the next table.

Table 18: *OSB Testing results*

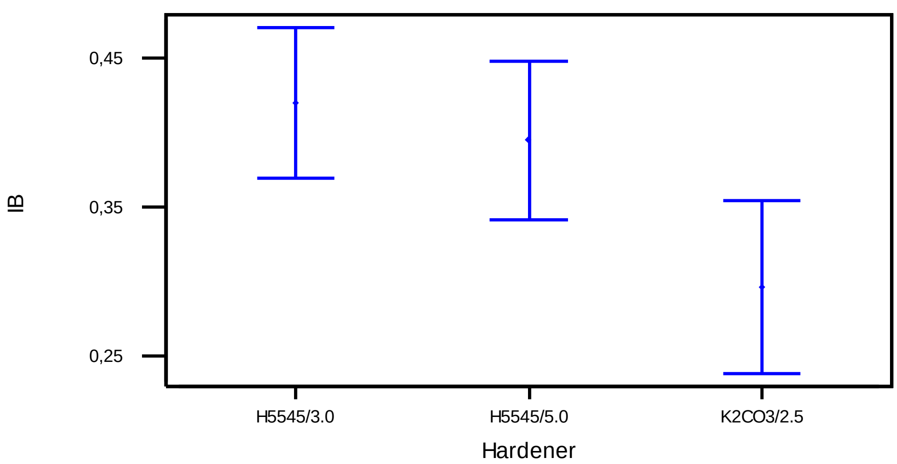
Press temperature, °C	180		
Press cycle, s/mm	12		
Hardener type and Level	K_2CO_3, 2.5	H5545, 3.0	H5545, 5.0
Thickness, mm	16.21	16.12	16.19
Density, kg/m³	507	503	517
IB, MPa	0.30	0.42	0.40
V100, MPa	0.13	0.19	0.17
TS, %	22.74	23.16	25.33
MOR, MPa	16.93	17.55	16.83
MOR-B, MPa	9.43	10.19	9.98
Perforator, mg/100g	3.18	2.23	1.76

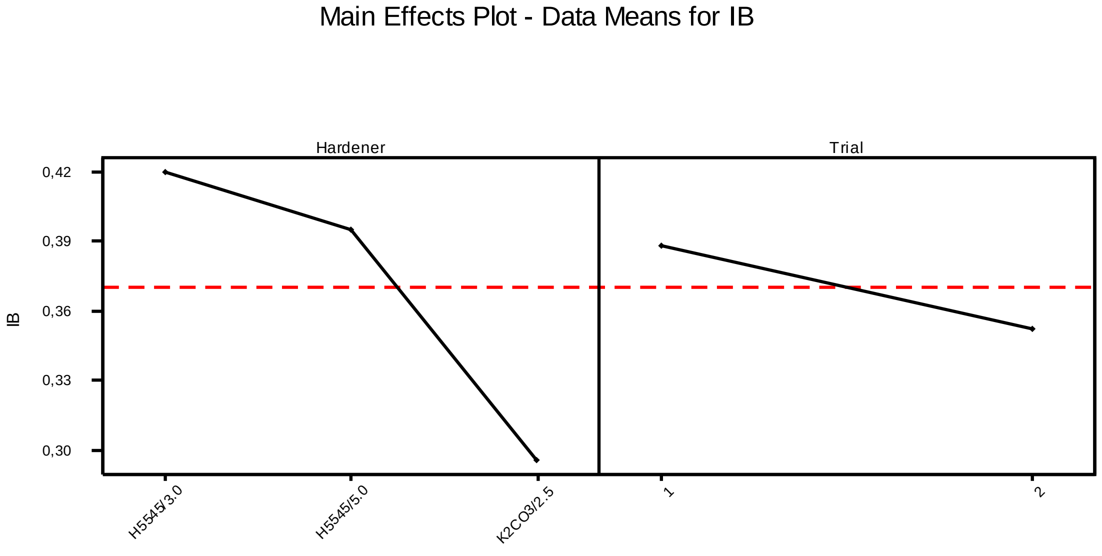
The ANOVA results obtained are the following:

```
Analysis of Variance for IB, using Adjusted SS for Tests

Source          DF    Seq SS    Adj SS    Adj MS      F      P
Hardener         2  0,103506  0,103506  0,051753  10,01  0,000
Trial            1  0,011736  0,011736  0,011736   2,27  0,142
Hardener*Trial   2  0,075706  0,075706  0,037853   7,32  0,003
Error           30  0,155150  0,155150  0,005172
Total           35  0,346097
```

The hardener type **is significant** factor for the IB at 95% confidence interval (P<0.050) and there is interaction between hardener type and number of the trial.

Internal plot for IB at 95% confidence interval



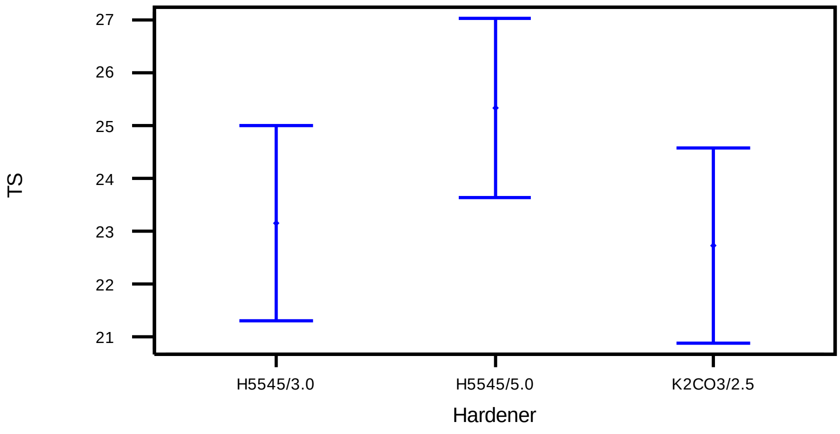


Analysis of Variance for TS, using Adjusted SS for Tests

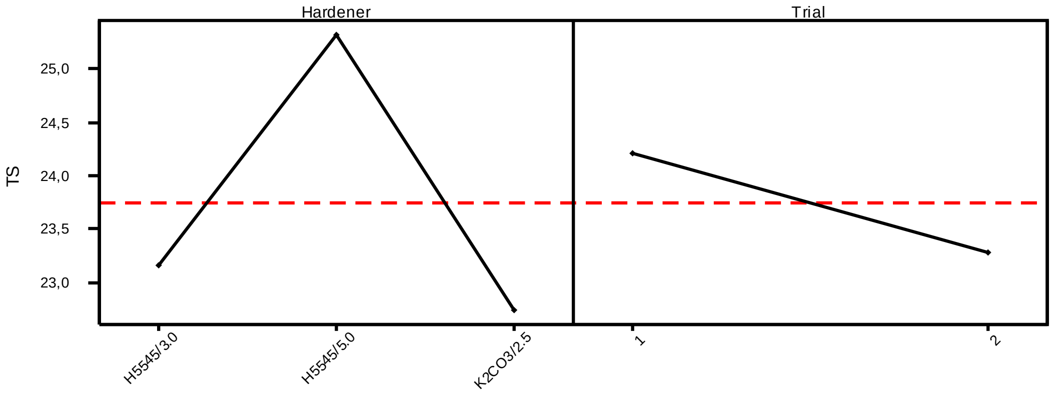
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Hardener	2	46,245	46,245	23,123	3,17	0,056
Trial	1	7,747	7,747	7,747	1,06	0,311
Hardener*Trial	2	35,643	35,643	17,821	2,44	0,104
Error	30	219,017	219,017	7,301		
Total	35	308,651				

None of the variables examined is significant for the swelling of the LSB panels.

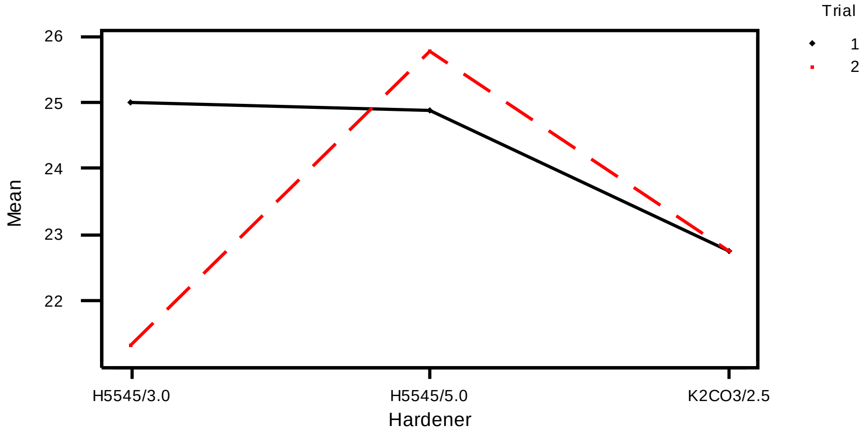
Internal plot for TS at 95% confidence interval



Main Effects Plot - Data Means for TS



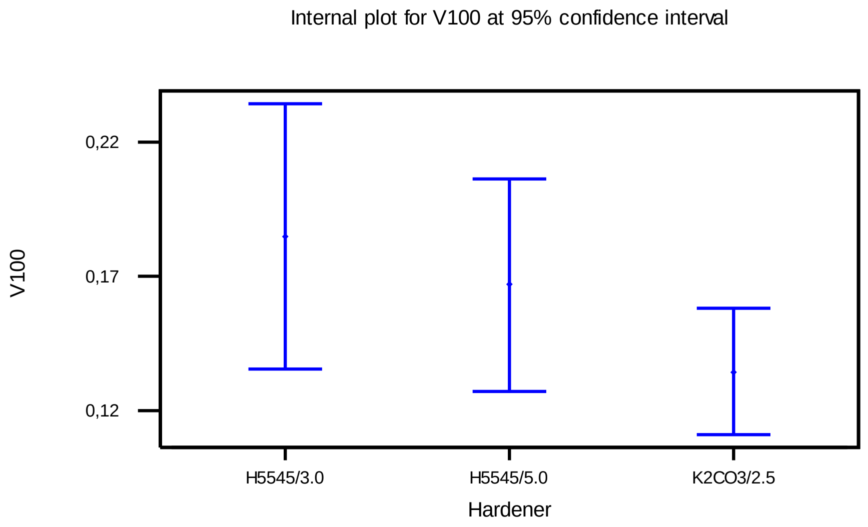
Interaction Plot - Data Means for TS

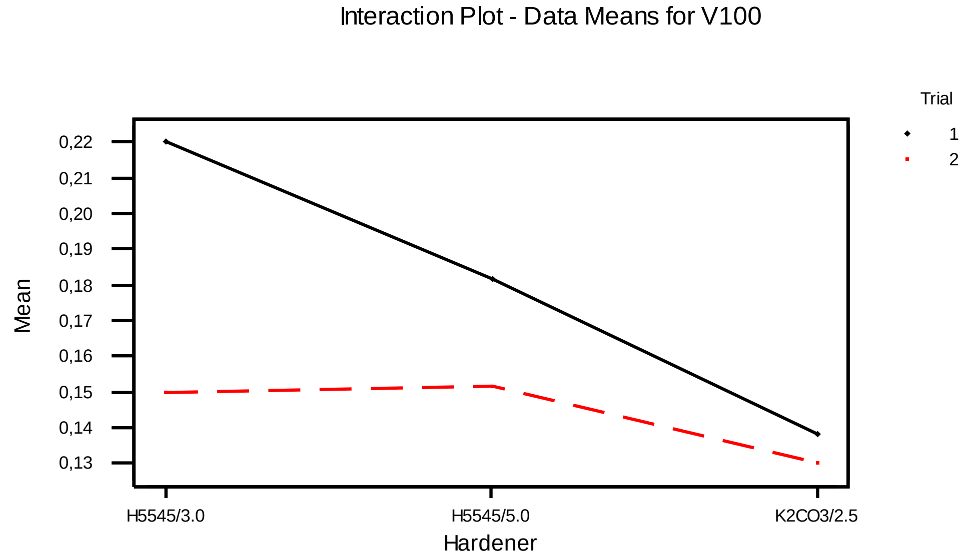


Analysis of Variance for V100, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Hardener	2	0,015906	0,015906	0,007953	2,21	0,127
Trial	1	0,011736	0,011736	0,011736	3,26	0,081
Hardener*Trial	2	0,005872	0,005872	0,002936	0,82	0,451
Error	30	0,107850	0,107850	0,003595		
Total	35	0,141364				

Neither the hardener type nor the trial number is significant for the V100 of the panels at 95% confidence interval.

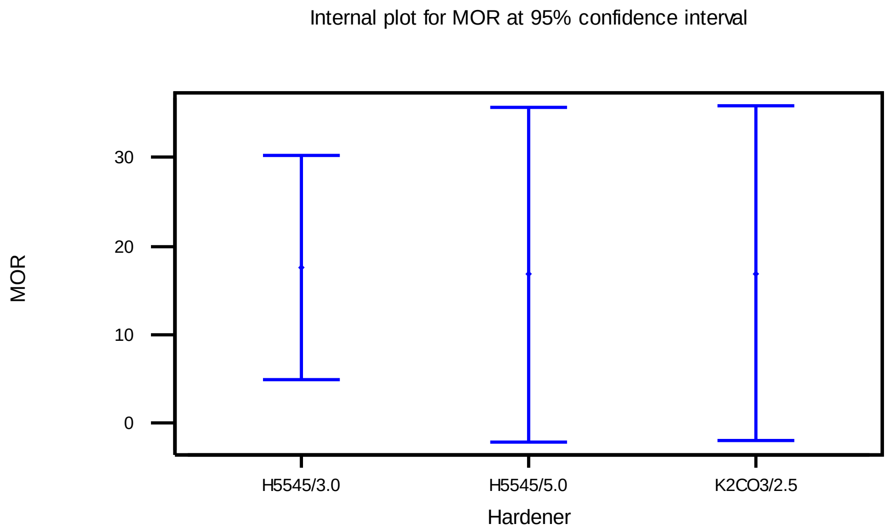


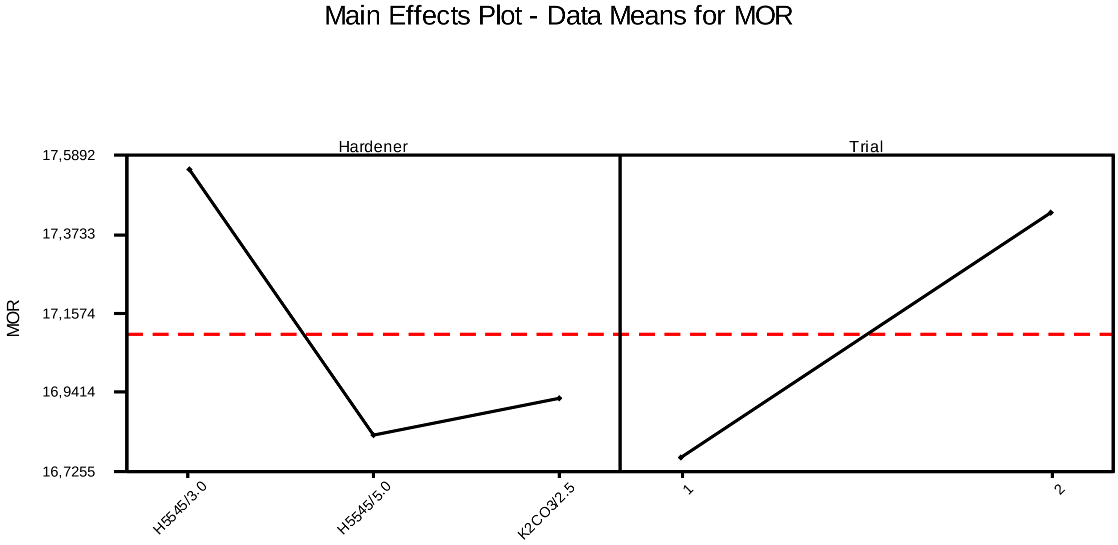


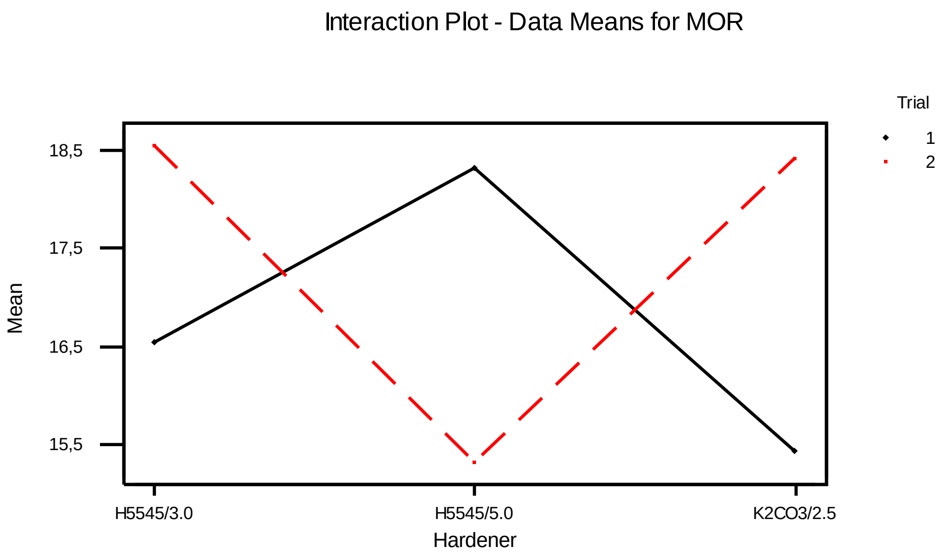
Analysis of Variance for MOR, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Hardener	2	0,617	0,618	0,309	0,06	0,943
Trial	1	0,667	0,667	0,667	0,13	0,753
Error	2	10,273	10,273	5,137		
Total	5	11,558				

Both factors examined, hardener type and number of board, are not significant for MOR of the panels.





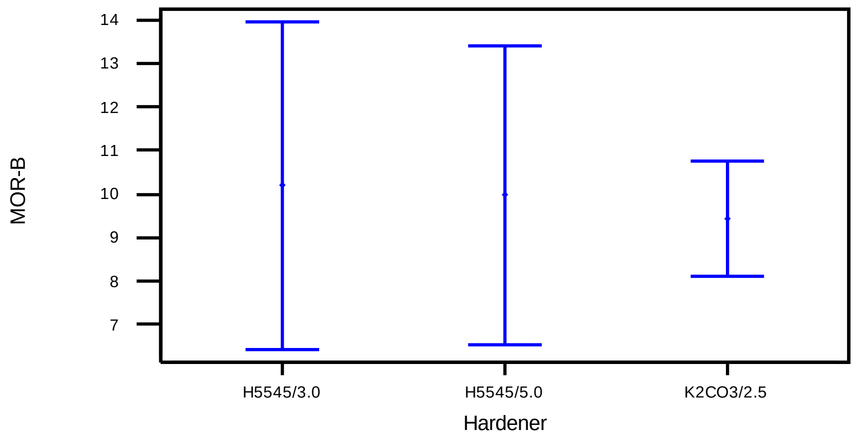


Analysis of Variance for MOR-B, using Adjusted SS for Tests

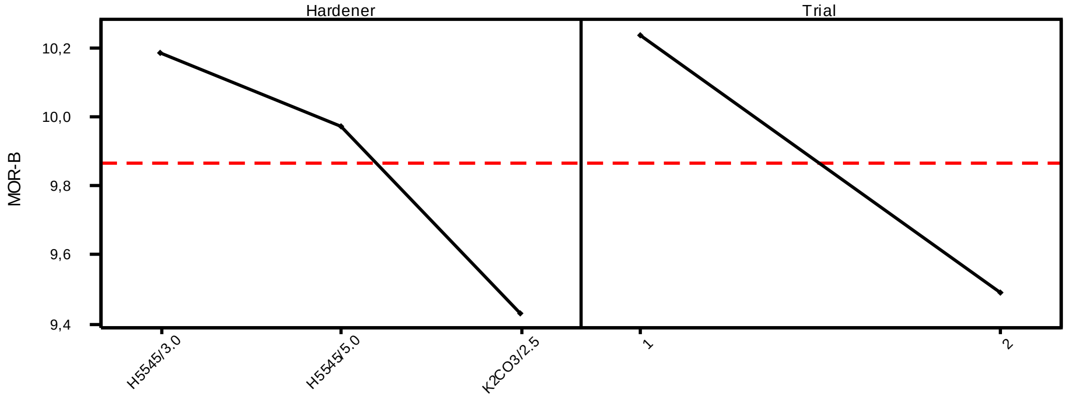
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Hardener	2	1,213	1,213	0,606	0,18	0,837
Trial	1	1,688	1,688	1,688	0,51	0,502
Hardener*Trial	2	11,552	11,552	5,776	1,75	0,252
Error	6	19,828	19,828	3,305		
Total	11	34,280				

None of the factors examined is significant for the MOR-B values of the panels.

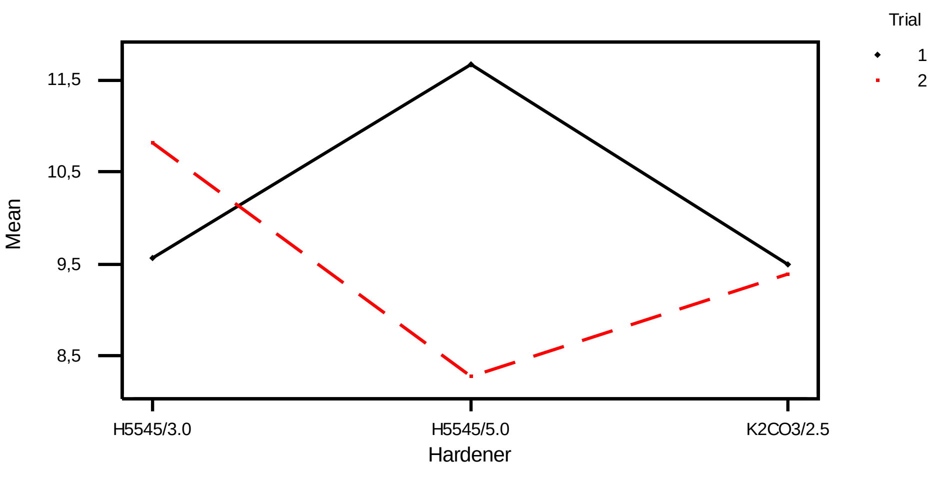
Internal plot for MOR-B at 95% confidence interval



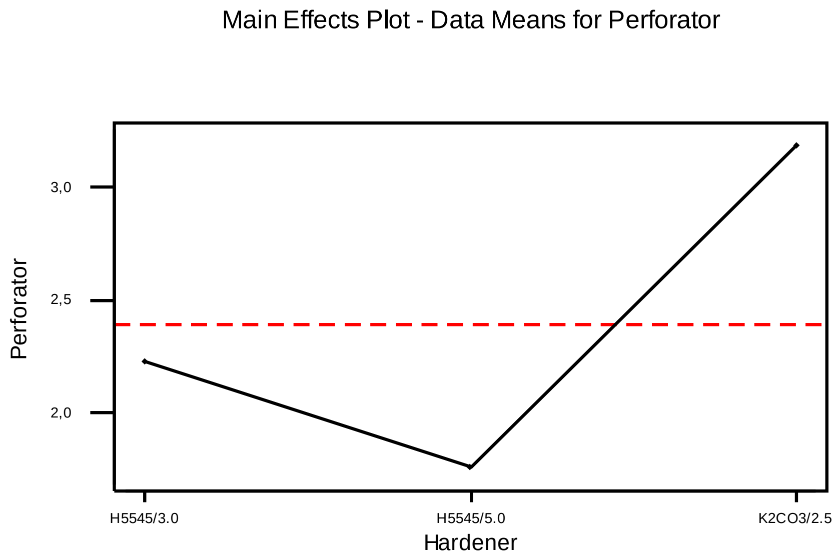
Main Effects Plot - Data Means for MOR-B



Interaction Plot - Data Means for MOR-B



As the formaldehyde content was determined only in the first trial, the data were not sufficient to carry out ANOVA. The main effect plot is shown below.



The testing values of the system with K_2CO_3 are just meeting the standard requirements for IB and V100, while both systems with H5545 are superior in all tests with the only exception the swelling values, which are 8-10 units higher than the standard requirements for all boards. This could be attributed either to the higher alkali content of the PF resin, or to the density of the panels which was >500kg/m^3 or to the very low formaldehyde content of the boards.

According to the ANOVA results, the type of hardener is statistically significant factor only for the IB. However, there is a trend that all the properties are improved when H5545 is used. It should be pointed out that the higher level of H5545 has a negative effect on the properties and this may be due to either the lower formaldehyde content or the pre-curing of the system.

The system with PF resin for the production of light weight OSB needs to be improved, e.g. possibly a higher MR of the resin and optimization of the hardener level should be tried. The effect of lower panel density, in the range of 450-500kg/m^3, should be evaluated too.

5 CONCLUSIONS/RECOMMENDATIONS

The results of the study performed revealed the following:

- It is feasible to produce at laboratory scale light weight OSB-type boards meeting the standard requirements for OSB/3 grade as well as the E1 formaldehyde class using poplar strands of I-214 clone supplied by the I-PAN partners and a binder system of MUPF resin with special additives.
- The press temperature was reduced by more than 10% without increasing the press cycle.
- The LSB production results were verified in extended lab trials.
- The effect of the reduced panel density on panel properties was investigated. It was found, that the lower the density of the panels, the worse the panel properties are. Increased resin loading can compensate the decrease in panel properties. The optimum resin loading can only be determined during a pilot or an industrial scale trial.
- LSB panels were produced using a PF type resin in combination with a hardener specially developed by CHIMAR.
- The press temperature and the press cycle for the PF-LSB were the same as those for the MUPF-bonded LSB.
- The use of special hardener is essential to obtain PF-bonded LSB with properties well beyond the standard requirements, with only exception the swelling of the panels.

The topics for further work include:

- To evaluate the effect of density in the range 450-500kg/m^3 on the overall performance of the LSB produced with PF resin.
- To optimize the PF resin system (e.g. optimize the hardener level).