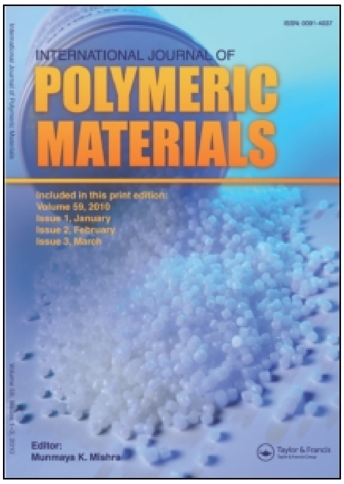

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LIGNOCELLULOSIC MATERIALS IN BUILDING ELEMENTS. PART IV—ECONOMICAL MANUFACTURE AND IMPROVEMENT OF PROPERTIES OF LIGHT-WEIGHT AGRO-PANELS

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This work is intended to promote the suitability of newsprint paper waste as one component of light-weight composite panels, using gypsum as a binder. The manufacture of agro-gypsum panels from corn stalks, a light lignocellulosic material, was taken as a basis for comparison. Promoting the newsprint paper involved carrying out two series of trials. First the authors studied the surface treatment of the cellulosic fibers before and during panel formation, using sodium silicate in combination with magnesium chloride, and then we added an acrylic polymer and/or replaced the gypsum by industrial waste, for example, phospho-gypsum or cement dust. Big improvements in the physicomechanical properties (low density, high water resistance, and compressive strength) of agro-gypsum panels can be obtained by replacing the gypsum with cement waste in the presence of the acrylic polymer. According to the compressive strength required, construction panels were manufactured from surface-treated waste paper with gypsum, and/or phospho-gypsum and cement dust, in absence or presence of acrylic polymer. Panels for thermal insulation were obtained from treated corn stalks and gypsum instead of waste paper. Addition of acrylic polymer or replacing the gypsum by phospho-gypsum or cement dust, improved the suitability of the corn stalks panels for construction applications.

Keywords: building elements, lignocellulose in building elements, light-weight building panels, agro-gypsum panels, waste paper as agro fibers, industrial wastes, phospho-gypsum, cement dust, interior application panels

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INTRODUCTION

The consumption of building materials will continue to increase with the expanding world population and increasing technological development. For this reason, modern building techniques use cemented or gypsum lignocellulosic bricks or panels to satisfy the increasing population, minimizing environmental pollution and economizing the consumption of natural resources. Most relevant recent publications are concerned with the production of cemented or gypsum lignocellulosic bricks or panels [1–10]. The most important problem arising has been the high water absorption of the bricks or panels, as a result of the hydrophilic nature of the lignocelluosic materials. For economic utilization, especially in partitions, the board or panels must have the following properties: high resistance to water, good resistance to compression, and good dimensional stability, as well as resistance to heat and fire.

Gypsum panels are frequently used to finish interior wall and ceiling surfaces. Gypsum is widely available and does not have the highly alkaline content of cement.

A series of papers has reported that low density gypsum products can be produced by mixing the gypsum with wood pulp and a resin sizing agent [1], lignocellulose and inorganic compounds or a plasticizer [2,6], a powdered cellulose and peroxide compound [7], or solid fibrous waste (e.g., waste bark) in the presence or absence of coal fly ashes [5]. Light-weight board is also produced by adding magnesium oxide and magnesium chloride to cement-methyl cellulose or pulp-water [11–12], or blending the cement and Nitobond AR (an acrylic polymer) with pre-treated wood processing residue [8]. The pre-treatment of wood residue was carried out by using linseed oil followed by thermal hardening.

The study described in this and earlier papers [8,13], aims to produce a new building element (light-weight construction panels), characterized by simple technique and economical enough to solve the housing problem in developing countries. These building elements are composed of lignocellulosic waste and cement or gypsum. From a survey of the amount of waste paper available in Egypt till year 2005 [14], it is clear that large amounts of waste paper are available for recycling in other applications rather than be used as a substrate for paper and cardboard manufacture (Table 1).

From the authors previous work [13], it can be said that although the waste paper treated with sodium silicate and magnesium chloride has fire retardant properties and the panels have a low density, their water resistance is still poor. In this work, the study was further

TABLE 1 Available Amounts of Waste Paper till Year 2005, in Egypt

Year	Consumed, tonne	Available for recycling, tonne	Used in recycling, tonne
1998	966	941	230
1999	1030	1003	300
2000	1100	1070	320
2005	1500	1460	440

extended to improve the physico-mechanical properties of the products while maintaining or even reducing their density. The effects of treating the waste paper before and during panel formation, adding an acrylic polymer, and replacing part of the gypsum by cheaper industrial wastes (phosphogypsum and cement dust) were examined. Composite panels manufactured from light-weight corn stalk as the agro component were used for comparison. In Egypt, corn stalk is accumulated in large amounts as an agricultural residue (~2.0 million tonne/year).

EXPERIMENTAL

Raw Materials

- Newsprint paper waste and corn stalks (grinding size 0.5 mm) were used in this study as lignocellulosic components in agro-gypsum panels. The chemical and physical properties of the lignocellulosic materials were determined by standard methods [15–18], and are given in Table 2.
- Gypsum was purchased from the Sina Co., El-Balah region, Egypt.
- Phospho-gypsum and cement dust were obtained from Abou-Zaable Fertilizers, and Helwan Cement Co., respectively. Their chemical compositions are presented in Table 3.
- Sodium silicate (3.5:1 molar ratio of SiO_2: Nas_2O), purchased from Riedel-De-ltaen Co., the Netherlands.

TABLE 2 Chemical and Physical Analyses of Agro-fibers Used

Analysis	Newsprint paper	Corn stalks
Ash content, %	7.32	4.47
α-Cellulose, %	64.54	56.47
Klason lignin, %	21.70	20.5
Pentosans, %	12.39	20.19
Water retention value, %	159.50	139.5

TABLE 3 Chemical Composition of Phospho-gypsum and Cement Dust

Phospho-gypsum		Cement dust	
SiO_2	5.14	SiO_2	14.19
$Al_2O_3 + Fe_2O_3$	0.85	Al_2O_3	4.25
CaO	31.47	Fe_2O_3	—
MgO	0.43	TiO_2	2.65
Na_2O	0.32	CaO	43.83
SO_3	41.98	MgO	1.80
P_2O_5	0.65	K_2O	4.50
H_2O	19.78	Na_2O	—
		SO_3	3.75
		IL	43.53

IL: ignition loss.

- Magnesium chloride was purchased from Adwic Chemical Co., Egypt.
- Nitobond AR (acrylic emulsion cement modifier and concrete bonding agent), was obtained from Fosroc Co., Egypt, and it possesses the following specifications:

Viscosity	: <500 mPa.s
Solid content	: 47%
Specific gravity (wet emulsion)	: 1.06
pH value	: 8.0–9.0
Emulsifying system	: Non-ionic
M.E.T.	: 10–20°C
Average particle size	: 0.1–0.2 microns

Manufacture of Agro-gypsum Panels

Based on the best results (relatively high water resistance, compressive strength and fire retardancy properties) obtained in the authors previous work [13], the following pretreatment of the lignocellulosic materials was adopted: lignocellulosic materials (newsprint paper and corn-stalks waste) were treated with 6% sodium silicate for two minutes followed by adding 6% magnesium chloride with kneading for three minutes. Panels were prepared by mixing the gypsum in a kneader with the treated lignocellulosic materials and water in the ratio of water to gypsum 0.83% by weight [19], followed by shaping in a mould with dimensions $70 \times 70 \times 70$ mm. The cubes produced were placed in a chamber for conditioning at 95% relative humidity and temperature 20–25°C for 28 days before testing [20].

The effects of treating the fibers before and during panel formation, adding different percentages of acrylic polymer (5–20 wt.) and replacing some of the gypsum by phospho-gypsum or cement dust were studied.

These replicates were prepared for each mixture.

Physical and Mechanical Testing of Agro-gypsum Panels

The panel density, dimensional changes, water absorption and compressive strength were measured by standard methods [20–21]. The water absorption and dimensional changes were measured after immersing the test specimen for 24 h at 20–22°C. The water level is maintained 5 cm high over the upper surface of the suspended specimens and the excess water was wiped off with damp cloth before weight measurements. The compressive strength is measured by using the hydraulic press "AMLER." The test specimens are exposed to the load until fracture occurred. Some of the samples show no fracture, but only creep. The fracture load is determined as (kg/cm^2) of the exposed face of the specimen. Each reading is the mean of three measurements.

RESULTS AND DISCUSSION

Effect of the Time of Treatment on the Agro Materials

Two sets of samples were prepared: one for assessing the effect of treating the agro fibers (newsprint paper waste and corn stalks), during the panel formation, and the another to examine the same treatment before panel formation. The physical and mechanical properties of the panels are recorded in Table 4.

Newsprint

For the case of newsprint waste fibers, Table 4 shows that panels prepared from pre-treated fibers with 6% sodium silicate and 6% magnesium chloride before mixing with gypsum possessed higher compressive strength and water resistance (low water absorption and dimensional change), and lower bulk density, than the panels prepared from fibers treated during the panel formation. This is probably related to the film (gel) formed around the hydrophilic cellulosic fibers by the sodium silicate and magnesium chloride. Treating the fibers before panel formation further enhanced this. This prevented the water absorption and the fiber swelling.

TABLE 4 Effect of Treating the Agro-fibers on the Properties of the Agro-gypsum Panels

Type of agro-fibers	Gypsum/ Fiber	Density Kg/m^3	Thickness swelling	Dimensional change, %	Water absorption	Compressive strength* MPa
Newsprint	100/0	770.0	1.63	1.93	73.5	1.096
Waste	70/30[a]	590.0	0.90	0.50	87.5	4.03
Paper	70/30[b]	575.8	0.78	0.41	80.27	4.13
Corn stalk	70/30[a]	612.0	2.37	2.78	109.8	0.69
	70/30[b]	593.0	1.97	2.67	107.9	0.79

[a]The fibers were treated during panel formation. [b]The fibers were treated before panel formation. *For the newspaper panels, the compressive strength is not the load at fracture, but the load required to produce deformation.

The panels prepared from 70% gypsum and 30% waste paper possessed lower bulk density, lower water resistance (higher water absorption and dimensional change) and higher compressive strength than panels produced from gypsum alone (100%). This can be attributed to the hydrophilic and porous nature of cellulosic fibers, in addition to the fact that blending gypsum with lignocellulosic fibers normally gives low mechanical properties [22–23].

Corn Stalks

For the case of corn stalks, Table 4 shows that the physical and mechanical properties of the panels made from fibers treated before mixing with gypsum have the same trend as newsprint waste fibers. The agro-gypsum panels obtained from mixing gypsum with treated corn stalks fibers have lower water resistance and compressive strength than those prepared from blending gypsum with treated waste paper fibers. The two types of panel have almost the same density.

Summing up the earlier results it can be concluded that pre-treatment of fibers with 6% sodium silicate and 6% magnesium chloride before mixing with gypsum is more successful in producing useful agro-gypsum panels than carrying out the treatment during the panel formation.

Effect of Acrylic Polymer Additive

The effect of adding different percentages of acrylic polymer, namely: 5, 10, 15 and 20% (based on the weight of panel), on the properties of the panels was examined. Panels made from 70% gypsum and 30% agro-fibers with water content of 0.83% [19] and pre-treated with the two solutions were used as controls.

From Figure 1 it is clear that the addition of the acrylic polymer emulsion (5–20%) improved the compressive strength, water resistance, and dimensional properties, as well as increasing the density, compared to the control panels. The maximum improvement in the compressive strength and water repellency was attained at 20 wt.% acrylic. For the case of treated newsprint-gypsum panels, the improvements in the case of thickness swelling, other dimensional change, water absorption, and compressive strength were 91.4%, 90.1%, 32.7%, and 33.4%, respectively. Increasing the weight of added acrylic from 5 to 20% (Figure 1a) caused a small increase in the panel density from 7.2 to 10.3%.

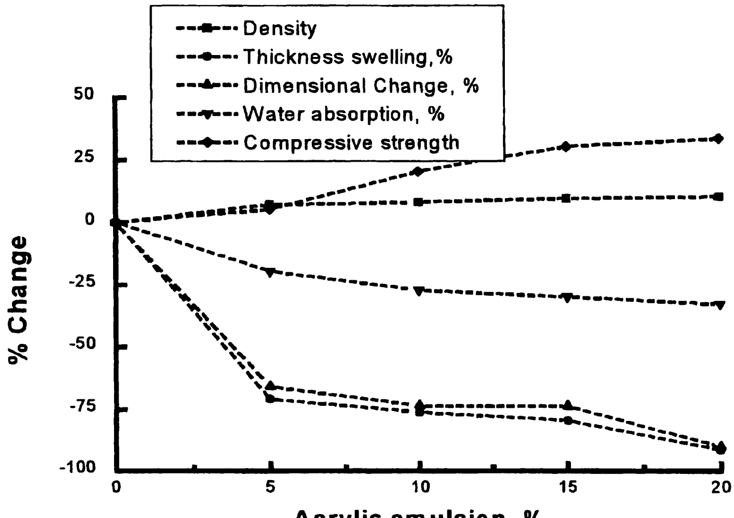
For the case of treated corn stalks–gypsum panels, Figure 1b shows that increasing the acrylic addition from 5 to 20 wt.%, during panel formation also leads to a gradual improvement in the panel properties. The optimum percentage change in the panel properties was also attained at 20 wt.% acrylic. The improvement in the water resistance of treated corn stalk–gypsum panels caused by adding acrylic was less than for newsprint-gypsum panels. The change in thickness swelling, other dimensions and water absorption in the former panels, with 20 wt.% acrylic, were −68.0%, −59.9%, and −31.9%, respectively. The reverse trend was noticed for the compressive strength, where the changes in the treated corn stalk–gypsum and treated waste paper–gypsum panels were 237.9% and 33.4%, respectively. Addition of acrylic increases the density of the corn stalk panels (4.3% compared to the control panel), but not to the same extent as in the case of the waste paper panel.

The improvement in the aforementioned properties is related to the properties of the acrylic additive, as recommended in Fosroc report. Whereas the acrylic is used as bonding aid (an excellent bond is achieved several hours after application), the curing agent improves the compressive strength, reduces the water losses and ensures good hydration. However, due to the decrease in panel porosity as a result of acrylic addition [24], an increase in the bulk density accompanied the acrylic emulsion addition, especially in the case of treated waste paper–gypsum panels.

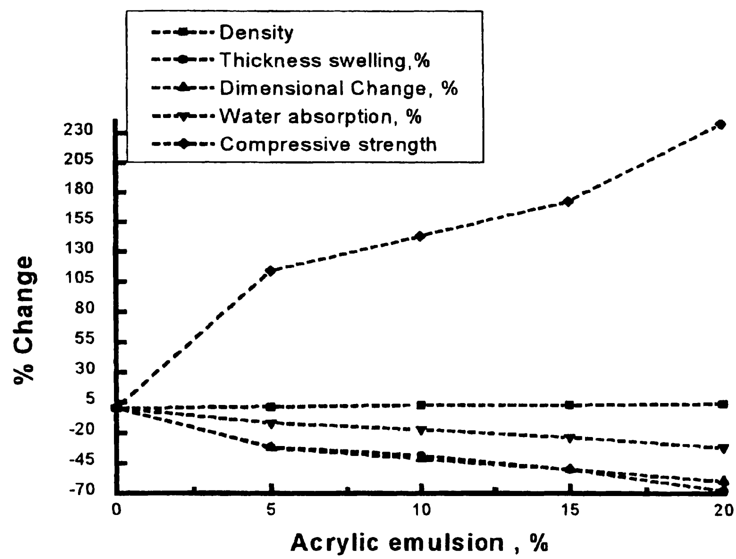
Effect of Phosphogypsum and Cement Dust

Replacing some of the gypsum with phospho-gypsum or cement dust wastes (20, 40, 80 and 100% based on weight of gypsum), was investigated. The results are illustrated graphically in Figures 2 and 3.

Gypsum to fibers (newsprint paper waste or corn stalks) ratio used in this study was 70:30 and the water content was 0.83%. The fibers



a-Waste paper-gypsum panels



b- Corn stalk-gypsum panels

FIGURE 1 Effect of acrylic emulsion addition on the physicomechanical properties of agro-gypsum panels.

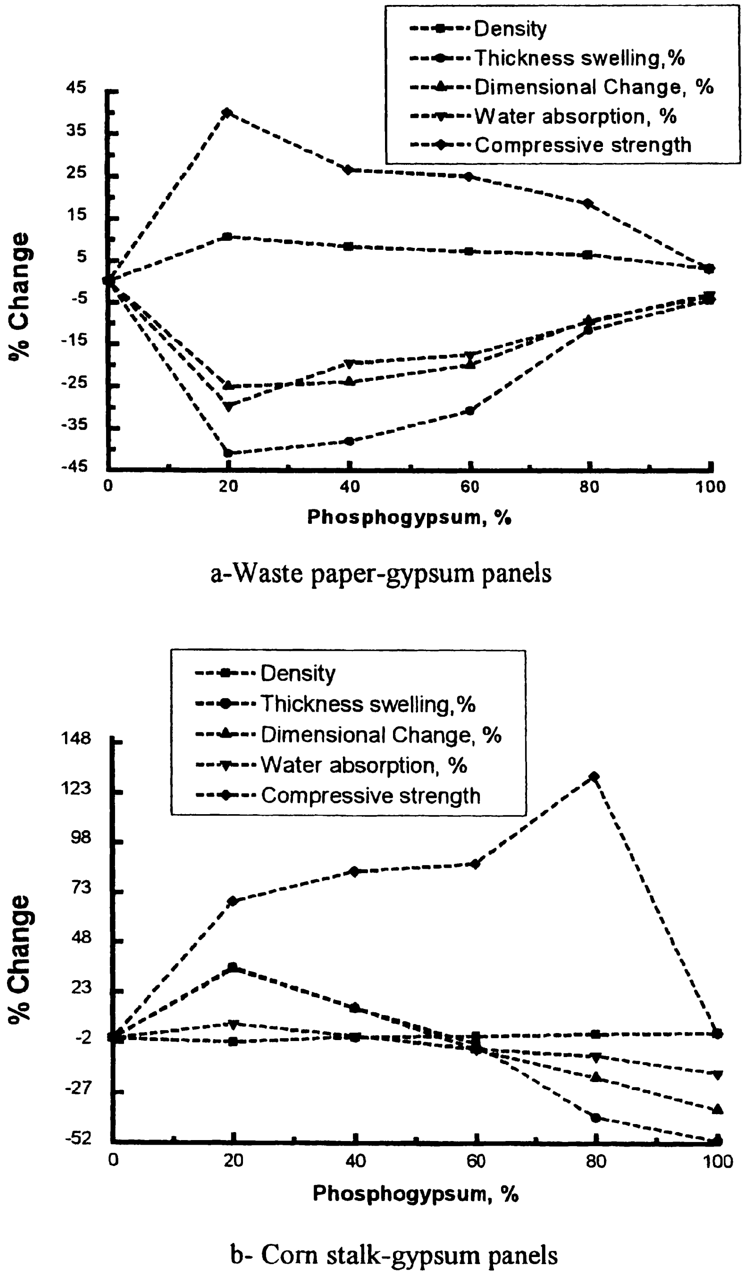
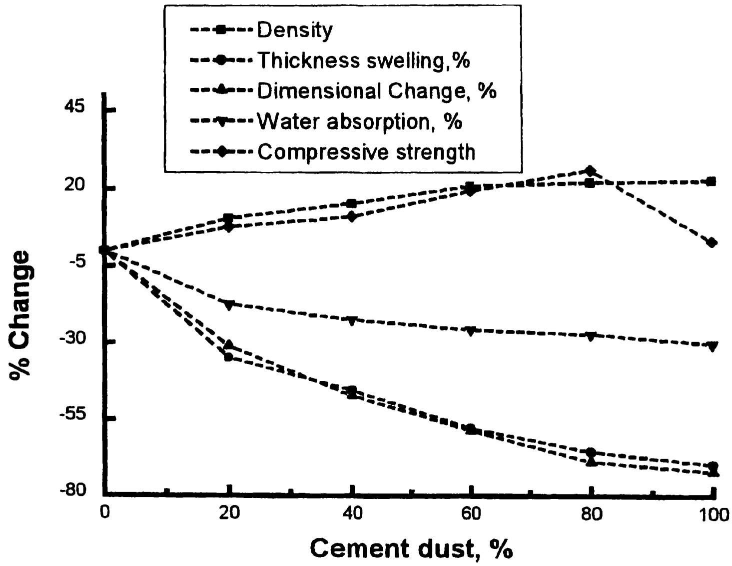
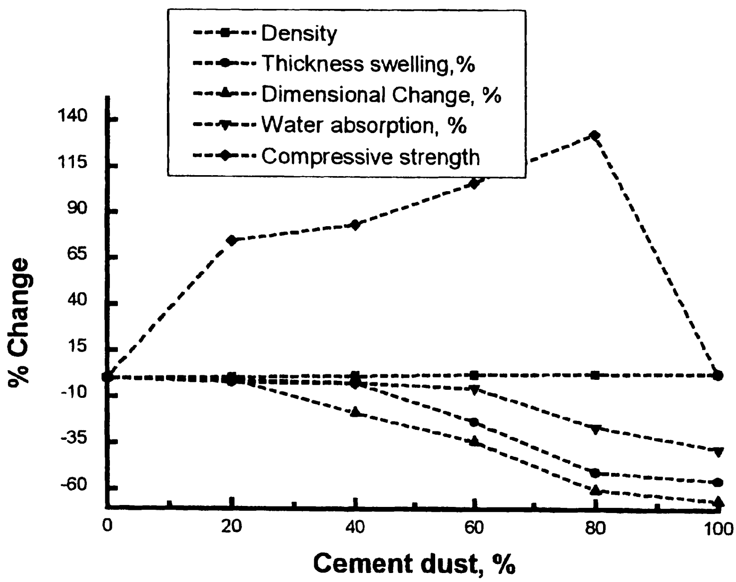


FIGURE 2 Effect of phosphogypsum on the physicomechanical properties of agro-gypsum panels.



a-Waste paper-gypsum panels



b- Corn stalk-gypsum panels

FIGURE 3 Effect of cement dust on the physicomechanical properties of agro-gypsum panels.

used in this study were pre-treated with sodium silicate and magnesium chloride before panel formation. Results for panels produced from 70% gypsum and 30% treated fibers are also included in this study for comparison.

Phosphogypsum Substitution

Figure 2 shows that replacing some of the gypsum by phosphogypsum during the formation of the panels increased the compressive strength and water resistance (low dimensional change and low water absorption). In addition there was an increase in the bulk density, compared to the control sample. The maximum change in panel properties was attained at 20% phospho-gypsum in the case of newsprint waste (Figure 2a).

On the other hand, the reverse trend was noticed in the case of cornstalk fibers when using low levels of phospho-gypsum (20 and 40%); Figure 2b. A slight decrease in the water resistance and bulk density and an increase in the compressive strength was observed, relative to treated fibrous-gypsum control panels. A further increase in the level of phospho-gypsum above 40% resulted in an improvement in panel properties. The optimum improvement was noticed with 100% phospho-gypsum, that is, replacing all gypsum.

The improvement in compressive strength and water resistance of the panels was more pronounced in the case of corn-stalks fibers than in the case of newsprint paper waste fibers. The percentages change of thickness swelling, dimensional change, and water absorption in the former panels are 146.8, −50.8, −35.2, and −16.9%, respectively, whereas in the latter panels they are 40, 41, −25, and −29.6%, respectively. However, the slight change (increase) in bulk density was less noticed in the former panels (% change 3.2%) than the latter panels (% change 10.6%).

Cement Dust Waste Substitution

For the case of substituting the gypsum by cement dust as cement waste, Figure 3 shows that replacing gypsum by cement dust during panel formation resulted in a sharp increase in both compressive strength and water resistance, in addition to a slight increase in the bulk density, compared with a control sample, as shown for newsprint fibers (Figure 3a). The maximum improvement was noticed at 100% cement dust. The increase in compressive strength, through-thickness swelling, dimensional change, and water absorption were 37.3, −70, −72.3, and −30.6%, respectively. Increasing the percentage of cement dust increases the panel density, till at 100% cement dust the maximum change is 22.7%.

For the case of corn-stalk fibers, the results of substituting cement dust waste for gypsum during panel formation are illustrated in Figure 3b.

As with newsprint paper panels, the substitution increases the bulk density, compressive strength, and water resistance. The extent of the increase in compressive strength in the case of corn stalks (% change 150%) is higher than that for newsprint paper waste (% change 37.3%). The reverse trend was noticed in the bulk density and water resistance.

Summing up the earlier results it can be concluded that, using phospho-gypsum and cement dust waste as industrial wastes instead of gypsum is more successful in producing lightweight agro-panels with good compressive strength and water resistance than gypsum and agro-gypsum panels. The improvement in the case of cement dust is higher than with phospho-gypsum.

Effect of Adding Acrylic to Agro Fibers with Gypsum and/or Industrial Wastes

The optimum conditions obtained (high compressive strength, low water absorption and low bulk density) from the previously mentioned results (Figures 1–3) were applied in this study. The effect of adding optimum amounts of acrylic (20 wt.%, from Figure 1) on the properties of agro-panels manufactured by mixing the pretreated agro-fibers with gypsum, or mixing it with the optimum amounts of gypsum with phospho-gypsum or cement dust (from Figures 2 and 3) is shown in Table 5, and compared with panels manufactured without acrylic and using gypsum alone.

From Table 5 it is clear that addition of 20 wt.% acrylic emulsion to either phospho-gypsum or cement dust wastes and agro-fibers mixture leads to an improvement in compressive strength and water resistance, compared with panels prepared with acrylic and replacing the gypsum by phospho-gypsum and cement dust. In addition this reduces the bulk density of the panels compared to panels from gypsum alone. The improvement in compressive strength and water resistance was more pronounced in the case of newsprint fibers than those produced from corn-stalk fibers. The optimum improvement in bulk density was greater with corn-stalks than newsprint paper waste.

From the compressive strength results it appears [25] that, agro-panels produced by adding acrylic emulsion and/or replacing some of gypsum by industrial wastes (phospho-gypsum or cement dust) can be used for construction. While panels prepared from treated corn stalks and gypsum can be used for thermoinsulation (C.S. 0.7–1.5 MPa),

TABLE 5 Effect of Adding Acrylic Emulsion on the Properties of Produced Panels made from Agro-fibers with Gypsum or with Gypsum and/or Industrial Wastes

		Without Nitobond (AR)					With Nitobond (AR)				
Type of Agro-fiber	Replacement	Density Kg/m^3	Thickness swelling %	Dimensional change %	Water absorption %	Compressive strength MPa	Density Kg/m^3	Through-thickness swelling %	Dimensional change %	Water absorption %	Compressive strength MPa
	100% Gypsum	770	1.63	1.93	73.50	1.096	—	—	—	—	—
Newspaper	—	575.8	0.78	0.41	80.28	4.13	635.0	0.07	0.04	54.03	5.51
Waste paper	20[a]	637.0	0.46	0.31	56.54	5.78	647.8	0.27	0.13	34.28	6.79
	100[b]	706.0	0.73	0.11	55.70	5.67	710.7	0.26	0.06	30.80	7.37
Corn stalk	—	593.0	1.97	2.67	107.9	0.79	618.5	0.63	1.07	73.50	2.67
	20[a]	612.0	0.97	1.73	89.7	1.95	627.3	0.93	1.07	61.70	3.58
	100[b]	610.5	0.89	0.92	67.3	1.98	629.8	0.75	0.73	37.30	4.37

Conditions of panels formation: — The ratio of agro-fiber to gypsum: 30/70. — The agro fibers used were treated by 6% Na_2SiO_3 + 6% $MgCl_2$ before panels formation. [a]The percentage of phosphogypsum replacement to gypsum. [b]The percentage of cement dust replacement to gypsum.

the panels from treated corn stalks with phospho-gypsum or cement dust, without adding Nitobond AR, can be used for construction and insulation (C.S. 1.5–20 MPa).

CONCLUSIONS

The following conclusions were obtained:

1. Agro-gypsum panels manufactured from pre-treating the fibers with 6% sodium silicate and 6% magnesium chloride had better properties than those produced by treating the agro-fibers during panel formation.
2. Addition of 5–20 wt.% acrylic emulsion improved the water resistance and compressive strength of agro-gypsum panels, and slightly increased the panel density. The maximum improvement in panel properties is attained at 20 wt. %.
3. Substitution of gypsum with phospho-gypsum or cement dust waste led to an increase in the bulk density, compressive strength, and water resistance of the panels. The improvement in the compressive strength and water resistance were more pronounced with cement dust than phospho-gypsum. Agro-panels manufactured from cement dust had a higher density than those prepared from phospho-gypsum.
4. Addition of acrylic emulsion to the mixture of agro-fibers with gypsum, or its blends with phospho-gypsum and cement dust, led to a further improvement in compressive strength and water resistance compared to panels prepared by adding acrylic resin or substituting the gypsum with industrial wastes.
5. The laboratory-manufactured panels suitable for construction applications are those manufactured from pre-treated newsprint with gypsum and/or phospho-gypsum and cement dust, in presence or absence of acrylic emulsion. Panels manufactured from pretreated corn stalks with gypsum or with the same aforementioned materials (acrylic and/or phospho-gypsum and cement dust) can be used in different applications, for example., thermo-insulation, construction insulation, and construction panels.

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