Thermal and mechanical properties of fabricated plaster of Paris filled with groundnut seed coat and waste newspaper materials for structural application

Földimogyoró héjjal és hulladék papírral készült szerkezeti felhasználású alabástromgipsz hőtani és mechanikai tulajdonságai

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Abstract

This work sought to assess the suitability of using boards produced with plaster of Paris (P.O.P) and various weight proportions of groundnut seed coat (GSC) as well as P.O.P and similar proportions of waste newspaper paste (WNP) as ceiling in building design. The results obtained from the investigation of thermal and mechanical properties of the fabricated boards revealed that with the use of GSC as filler, the samples were of higher mean values of specific heat capacity, thermal conductivity, thermal absorptivity, but lower mean values of bulk density, thermal diffusivity, percentage water absorption, flaking concentration and flexural strength when compared to the samples with similar proportions of WNP as filler content. Also, the sample with 13.8% content of GSC and the one containing 22.5% of WNP were found to exhibit an impressive performance. Generally, it was observed that the samples filled with either GSC or WNP were lighter than pure P.O.P samples and the recorded values for all the measured properties favoured them for use as ceiling material in buildings. It is noteworthy that the proportion of the filler can be adjusted for optimum performance of such environmentally-friendly and cost-effective ceilings. Utilizing groundnut seed coat and waste newspapers as filler materials in fabrication of P.O.P ceiling can help to reduce environment pollution level, ensure better thermal insulation of buildings and solve the lingering problem of high cost of using P.O.P or other conventional materials as ceiling in buildings by the end-users.

Keywords: ceiling, flaking concentration, flexural strength, recycling, specific heat capacity, thermal conductivity, waste materials

Kulcsszavak: födém, hajlító szilárdság, újrahasznosítás, fajlagos hőkapacitás, hővezető képesség, hulladék anyagok

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1. Introduction

In any building design, ceiling is one of the most important structural elements that require consideration with priority. Energy consumption increases as demand in thermal comfort of building raise [1]. Ceiling plays a vital role in shielding the occupant from direct heat absorbed from an external environment by the building roof. Stating in another way, ceiling is a finished surface that conceals the underside of a building roof to impart aesthetic appeal and also prevent thermal influx to the room, thereby promoting comfort as well as safety of individuals. Based on the used materials, various types of false ceiling include asbestos ceiling, gypsum ceiling, polyvinylchloride (PVC) ceiling, Plaster of Paris (P.O.P) ceiling, among others.

It has been reported that even at low concentration, asbestos has a significant health risk [2]. The findings made by [3, 4] also supported such report. Therefore, when considering the fact that gypsum ceiling can be easily damaged by water from a leaked roof and PVC ceiling is not heat-resistant, P.O.P ceiling becomes preferable among them. Usually, P.O.P is manufactured as a dry powder and when it is mixed with water, it is possible to produce paste which in turn is used for ceiling. The mixing process generates heat through crystallization and the hydrated P.O.P then hardens in mold after few minutes.

Apart from its attractive nature, P.O.P ceiling almost requires no maintenance and has a long-life-span. Such tendencies make it a suitable material for sustainability in real estate industry.

But sustainable building materials have to be cheap [5] in order to make housing affordable, accessible, easy to own and maintain [6, 7]. In that case, there is no doubt that the high cost of P.O.P experienced for years now has contributed immensely to the bane of development of housing in particular and construction sub-sector at large. Also, it is obvious that one way of solving the evolving problem due to high rise in the cost price of building materials is the production of new engineering materials that are cheap but can perform optimally when used for structural applications.

This research work, therefore, seeks to develop a new kind of composite material using P.O.P with groundnut seed coat (also known as testa) and waste newspaper (un-useful and discarded newsprint materials). The choice of groundnut seed coat and waste newspaper is primarily due to their cheap availability in addition to high volume generation as municipal solid wastes [8, 9] without safe disposal techniques. Kaz et al [10] opined that if this situation persists, the current annual production of about 2.01 billion metric tons of such solid wastes will increase by 70% with the possibility of their overall generation increasing to 3.40 billion metric tons by 2050 as estimated by world bank. Due to the global problems associated with solid waste management [11], it has been observed in recent times that the waste materials in question are usually disposed of by burning in an open air. This practice has the potential of bringing about serious environmental issues that can substantially affect human health and climate. Specifically, this work is aimed at using recycling method to prevent the accumulation of the said waste materials in our environment. The thermal and mechanical properties of the developed composite boards will be investigated in order to ascertain their suitability to be used as a ceiling in building design. Among other advantages, it is hoped that this work will provide useful information to engineers, builders, researchers and so on.

2. Experimental perspective

2.1 Materials

The following major materials were used in this research work; water, groundnut seed coat (collected from groundnut sellers as waste product of blanching process), waste newspapers (obtained from newspaper vendors) and P.O.P (ABS 3Se bought from building materials store). These materials were sourced within Uyo metropolis, Akwa Ibom State, Nigeria.

2.2 Method

2.2.1 Processing of the groundnut seed coat and waste newspapers

A large quantity of the as-received groundnut seed coat was soaked in cold water in a plastic bucket at 30°C. This process helped to remove any dirt and unwanted materials from it. After 10 hours, it was removed and sun-dried completely before being blended by means of an electric blender. Also, the waste newspaper was shredded into tiny pieces with the aid of an electrical paper shredder (Rexel V125). Warm water was put into another plastic bucket and the paper pieces produced were soaked in it for 24 hours. This was necessary in order to make the paper smooth, soft and unable to affect the amount of water needed for plaster reaction. On removing them from the water, they were lightly squeezed with hand (to remove some water absorbed) and then pounded by means of mortar and pestle to form paste. The paste was subjected to continuous sun-drying and weighing until its weight remained constant. *Fig. 1* shows the dry forms of the blended groundnut seed coast (GSC) and waste newspaper paste (WNP).

Fig. 1 Dry forms of (a) blended GSC and (b) WNP
1. ábra (a) GSC és (b) WNP szárított formában

2.2.2 Fabrication of test samples

Using hand lay-up technique, samples containing the P.O.P and various weight proportions of the blended groundnut seed coat were prepared. Then after, other samples of similar proportions but with the dry waste newspaper paste as content were formed. The weight ratio of water to the sample composition was 1:2 throughout the preparation process. While the prepared samples for thermal conductivity test were cast in a 240mm x 240mm x 18mm mold, those for other tests were poured into a mold of dimensions 210mm x 120mm x 10mm. For each composition, five representative samples were developed per proportion, precured for 40 minutes at room temperature and then sun-dried until there was no reduction in the weight of each of them before they were used for tests in this work.

2.3 Tests implementation

2.3.1 Bulk density

This property expresses the degree of compactness of matter in a given material considered. In this work, the sample was cut into a reasonable size and its mass was determined by weighing using analytical balance (METTLER TOLEDO, PL 203). Then after, the bulk volume of the sample was determined by modified water displacement method [12]. In this case, white candle wax discarded as waste was melted and used in surface-coating the sample. The thickness of the glass cylindrical tube was measured with digital micrometer screw gauge and the external diameter of the tube was measured using digital vernier calipers. Complete immersion of the coated sample was ensured after which the height through which water was displaced in the tube was measured with metre rule. The bulk density of the

sample (uncoated) was computed using the relation

$$\rho = \frac{M}{V_m - V_s} \quad (1)$$

where ρ = bulk density of the sample, M = mass of the sample, V_s = volume of the candle wax coating on the sample, V_m = volume of the coated sample and ($V_m - V_s$) = bulk volume of the sample.

2.3.2 Specific heat capacity

Determination of this property was done by using mixture method of calorimetry, employing temperature-cooling correction [13, 14]. However, instead of using boiling water to heat the sample under investigation, a modified procedure was applied in this work. The mass of an empty copper calorimeter with its stirrer and that of the sample were measured. After filling the calorimeter with a reasonable amount of cold water, the mass of the water alone was determined. Then after, the system was well lagged and its initial temperature was measured by means of a copper-constantan thermocouple. Also, a stainless-steel container was filled to about 18mm of its depth with dry sharp river sand (free from impurities) screened with mesh No. 10 of US sieve. The sample was embedded in the sand in such a way that it did not make any direct contact with the container. While heating the container, when the temperature of its content remained unchanged for some seconds, the sample was quickly transferred by tongs into the water contained in the calorimeter. In order to determine the actual final steady temperature of the gently stirred mixture, the temperature-cooling correction value was added to the observed steady temperature value. Also, for any component of the system, the quantity of heat lost or gained in the process, as the case may be, was calculated as the product of its mass, specific heat capacity and change in temperature (in relation to the actual final temperature of the mixture). By assuming that there were no heat losses to the surroundings, the specific heat capacity, c of the sample was calculated using the formula

$$c = \frac{Q_c + Q_w}{M\Delta T} \quad (2)$$

where Q_c = quantity of heat gained by the calorimeter and its stirrer, Q_m = quantity of heat gained by water in the calorimeter, M = mass of the sample used and $\Delta\Theta$ = change in temperature of the sample on cooling.

2.3.3 Thermal conductivity and thermal diffusivity

Measurement of data for determination of thermal conductivity of each sample in this work were carried out in accordance with ASTM C518 procedure [15]. The data were obtained using Heat Flow Meter (HFM 100 series) as described elsewhere [16]. This meter is equipped with Peltier heating / cooling plates for rapid temperature control. Its two flux sensors are for accurate monitoring of heat flux generated as a result of difference in temperature between the top and bottom plates at regular intervals. Based on Fourier's law, when the steady-state heat flux was observed, the data obtained were applied to calculate the sample's thermal conductivity value according to the relation

$$k = \frac{xQ}{A\Delta\theta} \quad (3)$$

where k = thermal conductivity of the sample, x = thickness of the sample, Q = amount of heat flowing through the sample, and $\Delta\Theta$ = temperature difference between the top and bottom plates.

For each of the samples, the values of thermal conductivity, bulk density and specific heat capacity got were used to compute its thermal diffusivity, λ as [17]

$$\lambda = \frac{k}{\rho c} \quad (4)$$

2.3.4 Water absorption

Porous ceiling materials are known to have the tendency to absorb and retain water if it gets in contact with them. Since, as ceiling materials, the samples are likely to come in contact with water if there is leakage in the building roof, this test was performed to assess the extent to which the samples in this work can behave in such situation, Each dry sample was weighed before all of them were immersed immediately in water at 32°C. After 24 hours, they were removed from the water and allowed to surface-dry before each of them was reweighed. The data obtained were used to determine the percentage water absorption based on the equation [16]

$$W.A = \left(\frac{M_w - M_d}{M_d}\right) 100\% \quad (5)$$

2.3.5 Flaking concentration and flexural strength

The durability of materials that can undergo tear and wear when they are worked on can be predicted from the degree of their abrasion resistance. Such prediction is possible with a known value of a material's flaking concentration. In this work, a Taber Linear Abraser (Model 5750) was used for the test. The machine has a mechanical arm to which a free-floating test system is attached. Both sides of the sample were cleaned using a lint free cloth after which the mass of the sample was measured. The sample was then placed on the table and secured with sample holder in such a way that the area to be tested lined up with the abradant. Also, the abradant was refaced with a bristled brush pad before the commencement of the test. For each of the test samples, a test speed of 70 strokes per minute was used with 50 cycles of back-and forth movement of the arm. At the end of each test, both sides of the sample (flaked) were cleaned and the sample was weighed. The data obtained were utilized in the calculation of flaking concentration using the formula

$$F_c = \frac{m_f}{m_o} \quad (6)$$

where F_c = flaking concentration of the sample, m_f = difference in the mass of the sample after the abrasion test, m_o = mass of the sample before being subjected the abrasion test.

The flexural strength was tested for each of the samples using a three-point bending method as stated in [18]. A test speed of 50.0mm.min^{-1} was maintained for each test schedule until fracture occurred [16]. Then the value of maximum load, L applied at that instant, length of the support span, d as well as the width, b and thickness, x of the sample were applied in the computation of flexural strength, σ as

$$\sigma = \frac{3Ld}{2bx^2} \quad (7)$$

All the tests in this work were carried out at room temperature with ± 2°C variations. For each test, the five representative samples developed were made use of and also, the results obtained were tabulated and analysed.

3. Results and discussion

The experimental data got from the analysis involving samples with groundnut seed coat (GSC) and those associated with samples containing waste newspaper paste (WNP) are recorded in *Table 1* and *Table 2* respectively. For 0.0% content of either GSC or WNP, the data are meant for pure plaster of Paris (P.O.P) samples. The mean values of the data are presented, with their uncertainty, as the experimental results in *Table 3*.

It can be seen from *Table 3* that the addition of either GSC or WNP to the P.O.P decreases the mean values of bulk density and thermal conductivity. Samples containing the GSC are observed to have lower values of mean bulk density and higher values of mean thermal conductivity than their counterparts containing the WNP. In the case of bulk density, this shows that the densest material among the three is P.O.P followed by WNP. Also, in the case of thermal conductivity, it is due to the capability of the WNP to create more pores within the samples and that consequently gives rise to existence of more enclosed dead air space (void) after the fabrication process. Thus, since air is a poor conductor of heat, the samples with WNP content then become more thermally insulating than those containing GSC of similar proportion. As can be deduced from *Table 3*, the mean thermal resistivity (reciprocal of mean thermal conductivity) value of the P.O.P is (3.829 ± 0.059) W^{-1}mK while the highest mean value for the samples with GSC content and the highest mean value for the samples containing WNP are (6.557 ± 0.013) W^{-1}mK and (8.097 ± 0.118) W^{-1}mK respectively. These mean thermal resistivity values portray improvement in thermal insulation ability at 31.3% by (41.62 ± 0.92) % for GSC content and (52.72 ± 1.80) % for using WNP as a component of the samples. The implication of this observation is that although the developed samples with GSC are lighter than those with WNP content of similar proportion, they are not as effective as the later in terms of ability to restrict heat transmission across their thickness.

From *Fig. 2*, it is obvious that the mean values of both bulk density and thermal conductivity decrease with the proportion of either GSC or WNP added to the P.O.P. This finding is fully supported by the report of Faiza et al [19]. The possibility of this phenomenal trend is based on the fact that since the size of the fabricated samples is fixed in this work, increasing the GSC or WNP content leads to decrease in the proportion of the P.O.P which eventually results to decrease in bulk density of the sample because of increase in its number of interstices through which air may pass easily.

Weight fraction of GSC	Sample Code	Bulk Density, ρ (kgm^{-3})	Specific Heat Capacity, c ($Jkg^{-1}K^{-1}$)	Thermal Conductivity, k ($Wm^{-1}K^{-1}$)	Thermal Diffusivity, λ ($10^{-7}m^2s^{-1}$)	Water Absorption, W.A (%)	Flaking Concentration, F_c (10^{-3})	Flexural Strength, σ (N/mm^2)
0.0%	S1	1360.89	1586.34	0.2637	1.221	13.28	0.038	5.230
	S2	1353.29	1622.85	0.2528	1.151	14.24	0.041	5.210
	S3	1363.83	1577.34	0.2730	1.269	12.92	0.037	5.236
	S4	1356.62	1596.66	0.2539	1.172	14.08	0.040	5.211
	S5	1360.49	1610.69	0.2625	1.198	13.68	0.038	5.217
7.5%	G1	1175.00	1757.81	0.2347	1.136	15.87	0.778	1.343
	G2	1162.00	1775.95	0.2267	1.099	15.99	0.779	1.342
	G3	1152.66	1820.70	0.2182	1.040	16.02	0.919	1.330
	G4	1154.46	1817.58	0.2257	1.076	16.00	0.848	1.333
	G5	1150.21	1831.46	0.2173	1.032	16.04	0.991	1.322
13.8%	G6	1011.79	2000.80	0.1800	0.889	20.45	1.277	0.525
	G7	1020.91	1953.55	0.1808	0.907	20.23	1.226	0.526
	G8	1030.14	1952.00	0.1934	0.962	19.52	1.097	0.543
	G9	1027.48	1948.98	0.1873	0.935	19.73	1.157	0.540
	G10	1025.73	1949.28	0.1865	0.933	19.95	1.212	0.528
22.5%	G11	898.99	2207.74	0.1680	0.847	22.54	1.533	0.460
	G12	924.07	2177.33	0.1744	0.867	22.47	1.524	0.501
	G13	899.77	2200.96	0.1688	0.852	22.53	1.530	0.477
	G14	927.64	2170.69	0.1796	0.892	22.45	1.473	0.503
	G15	922.89	2186.34	0.1736	0.860	22.49	1.529	0.480
31.3%	G16	843.89	2460.21	0.1524	0.734	29.15	2.192	0.165
	G17	856.69	2409.97	0.1533	0.743	29.12	2.188	0.169
	G18	842.32	2466.89	0.1521	0.732	29.21	2.274	0.162
	G19	851.66	2438.81	0.1527	0.735	29.13	2.191	0.167
	G20	839.83	2484.61	0.1518	0.727	29.26	2.281	0.160

Table 1 Experimental data from the analysis involving the samples with GSC
1. táblázat A GSC-vel készült mintákon végzett vizsgálatok mérési eredményei

Weight fraction of WNP	Sample Code	Bulk Density, ρ (kgm^{-3})	Specific Heat Capacity, c ($Jkg^{-1}K^{-1}$)	Thermal Conductivity, k ($Wm^{-1}K^{-1}$)	Thermal Diffusivity, λ ($10^{-7}m^2s^{-1}$)	Water Absorption, W.A (%)	Flaking Concentration, F_c (10^{-3})	Flexural Strength, σ (N/mm^2)
0.0%	S1	1360.89	1586.34	0.2637	1.221	13.28	0.038	5.230
	S2	1353.29	1622.85	0.2528	1.151	14.24	0.041	5.210
	S3	1363.83	1577.34	0.2730	1.269	12.92	0.037	5.236
	S4	1356.62	1596.66	0.2539	1.172	14.08	0.040	5.211
	S5	1360.49	1610.69	0.2625	1.198	13.68	0.038	5.217
7.5%	W1	1217.41	1566.20	0.2106	1.105	20.99	1.433	3.058
	W2	1222.95	1561.85	0.2116	1.108	20.82	1.544	3.068
	W3	1209.95	1567.98	0.2074	1.093	21.08	1.374	3.052
	W4	1189.99	1597.57	0.2063	1.085	21.16	1.491	3.049
	W5	1189.87	1604.56	0.2053	1.075	21.34	1.436	3.040
13.8%	W6	1088.63	1553.25	0.1783	1.054	27.08	2.081	2.397
	W7	1090.14	1545.17	0.1792	1.064	26.98	2.043	2.403
	W8	1081.17	1558.23	0.1767	1.049	27.19	2.082	2.386
	W9	1116.09	1534.21	0.1829	1.068	26.69	1.985	2.424
	W10	1098.66	1543.49	0.1804	1.064	26.88	1.986	2.418
22.5%	W11	1049.54	1531.35	0.1457	0.907	33.79	4.279	1.258
	W12	1028.34	1549.92	0.1378	0.865	33.77	4.331	1.251
	W13	1036.59	1535.01	0.1381	0.868	33.77	4.332	1.279
	W14	1051.55	1529.49	0.1463	0.910	33.88	4.279	1.279
	W15	1055.59	1520.73	0.1484	0.924	34.14	4.199	1.283
31.3%	W16	936.15	1505.64	0.1274	0.904	41.87	7.713	0.858
	W17	913.78	1521.79	0.1183	0.851	43.00	7.891	0.845
	W18	922.01	1514.25	0.1253	0.897	42.54	7.790	0.850
	W19	919.54	1521.36	0.1198	0.856	42.78	7.878	0.848
	W20	927.19	1512.15	0.1269	0.905	41.96	7.721	0.852

Table 2 Experimental data from the analysis involving the samples with WNP
2. táblázat A WNP-vel készült mintákon végzett vizsgálatok mérési eredményei

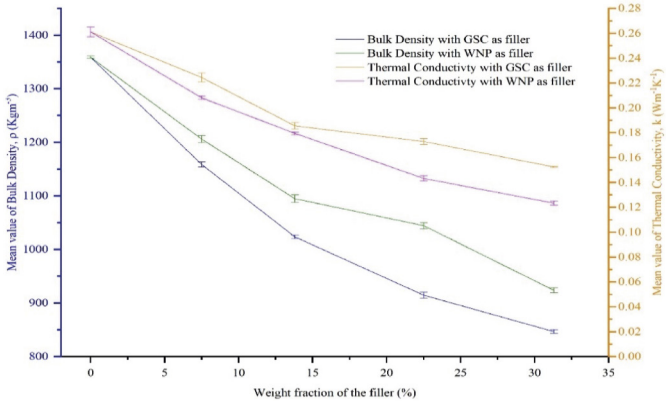

Fig. 2 Mean values of bulk density and thermal conductivity with filler proportion added to P.O.P.
2. ábra Testsűrűség valamint hővezető képesség az alabástromgipszhez adagolt kitöltőanyag mennyiség függvényében

The results registered in *Table 3* also reveal that, while increase in the proportion of GSC causes increase in the mean specific heat capacity values of the samples, the reverse is shown when the content of WNP increases. This portrays the fact that the specific heat capacity value of the P.O.P is less than that of GSC but greater than that of the WNP. It means that more heat will be required by samples containing GSC than those fabricated with WNP content in order to effect a change in the temperature of their unit mass.

In the case of thermal diffusivity, the mean values for samples containing GSC are slightly lower than those recorded for the samples with WNP content. This may be attributed to the GSC having a higher value of specific heat capacity than that of WNP. Despite the opposite trend observed in terms of the mean specific heat capacity values, a direct relationship exists between the mean values of thermal diffusivity and thermal conductivity with respect to the variations in the contents for both cases of GSC and WNP in the prepared samples. The fact portrayed by such link involving thermal conductivity and thermal diffusivity is that as the ability of the samples to allow heat pass across their thickness decreases, the speed at which such heat diffuses through them decreases as well. This is certainly in agreement with their mathematical relationship adopted (for use) and expressed as equation 4 in this work. By considering the reported thermal diffusivity value of 1.8 – 2.0 × $10^{-7}m^2s^{-1}$ for dry wood panel products [20], there is no doubt that although the spread of heat will be slower within samples with GSC component than in their counterparts containing WNP, the samples (used in this work) have lower rates of distribution of thermal disturbance than dry wood panel products.

Moreover, samples developed with the WNP as filler have higher values of mean water absorption than those containing the GSC. This may be due to the impermeable tendency of GSC and hydrophilic nature of WNP. In other words, the WNP has

Waste Content	Weight Fraction n	Mean values of the test properties						
		Bulk Density, ρ (kgm^{-3})	Specific Heat Capacity, c ($Jkg^{-1}K^{-1}$)	Thermal Conductivity, k ($Wm^{-1}K^{-1}$)	Thermal Diffusivity, λ ($10^{-7}m^2s^{-1}$)	Water Absorption, W.A (%)	Flaking Concentration, F_c (10^{-3})	Flexural Strength, σ (N/mm^2)
GSC	0.0%	1359.02 ± 2.11	1598.78 ± 9.10	0.2612 ± 0.0040	1.202 ± 0.024	13.64 ± 0.26	0.039 ± 0.001	5.221 ± 0.005
	7.5%	1158.87 ± 4.96	1800.70 ± 14.73	0.2245 ± 0.0035	1.077 ± 0.021	15.98 ± 0.03	0.863 ± 0.043	1.334 ± 0.004
	13.8%	1023.21 ± 3.67	1960.92 ± 10.36	0.1856 ± 0.0027	0.925 ± 0.015	19.98 ± 0.19	1.194 ± 0.036	0.532 ± 0.004
	22.5%	914.67 ± 5.73	2188.61 ± 7.41	0.1729 ± 0.0023	0.864 ± 0.009	22.50 ± 0.02	1.518 ± 0.011	0.484 ± 0.009
	31.3%	846.88 ± 3.37	2452.10 ± 14.93	0.1525 ± 0.0003	0.734 ± 0.003	29.17 ± 0.03	2.225 ± 0.019	0.165 ± 0.002
WNP	0.0%	1359.02 ± 2.11	1598.78 ± 9.10	0.2612 ± 0.0040	1.202 ± 0.024	13.64 ± 0.26	0.039 ± 0.001	5.221 ± 0.005
	7.5%	1206.03 ± 6.62	1579.63 ± 8.54	0.2082 ± 0.0013	1.093 ± 0.007	21.08 ± 0.10	1.456 ± 0.034	3.053 ± 0.006
	13.8%	1094.94 ± 6.98	1546.87 ± 4.81	0.1795 ± 0.0012	1.060 ± 0.004	26.96 ± 0.10	2.035 ± 0.019	2.406 ± 0.008
	22.5%	1044.32 ± 5.45	1533.30 ± 5.84	0.1433 ± 0.0021	0.895 ± 0.012	33.87 ± 0.07	4.284 ± 0.027	1.265 ± 0.006
	31.3%	923.73 ± 4.47	1515.04 ± 3.23	0.1235 ± 0.0018	0.883 ± 0.011	42.43 ± 0.23	7.799 ± 0.036	0.851 ± 0.003

Table 3 Statistics of the measured properties of the samples
3. táblázat A vizsgált tulajdonságok mérési eredményeinek statisztikai elemzése

a stronger affinity for water compared to the GSC. The nature of both GSC and WNP also plays a critical role in the abrasion resistance of the prepared samples. As can be seen from the results presented in *Table 3*, the flaking concentration increases with the filler content and results in the highest recorded mean value at 31.3% content of the GSC or WNP. Based on the value of 2.0×10^{-2} reported by Berge [20] to be the flaky concentration of asbestos, it can be rightly remarked that the samples developed in this work are less flaking than asbestos by at least (88.87 ± 0.09) % with GSC content and (61.00 ± 0.18) % with WNP as component. This simply means that the said samples are better than asbestos in maintaining their original structure and appearance by resisting mechanical wear. Although the abrasion resistance is higher in the case of using GSC than that of WNP as fillers, the samples with WNP content exhibit better flexural strength than those formed with similar proportion of GSC.

Fig. 3 clearly depicts how the mean percentage values of water absorption as well as mean flexural strength values vary with the proportion of the filler used. For instance, it can be deciphered that as the mean percentage values of water absorption increase with the added proportion of the GSC or WNP, a slight stability tends to occur between 13.8% and 22.5% of the filler content in the case of samples containing GSC. On the contrary, the mean values of flexural strength decrease with increase in the filler proportion and this observation resonates with the research findings reported by Al-Shabander [21].

In general, the results obtained in this work reveal that the mean thermal conductivity values of the samples fall within the range (0.023 – 2.900) $Wm^{-1}K^{-1}$ recommended by [22], for good heat-insulating and construction materials. Also, all the materials fabricated with either the GSC or WNP content are lighter than the pure P.O.P sample and this is an enviable characteristic of the new engineering material sought for. Again, at 0.05 level of significance, Chi-square test of the recorded results reveals that there is a significant effect of varying the proportion of the fillers on the samples' mean values of the properties investigated. Though the mechanical performance reduces as the thermal properties of the samples improve, it is likely that the sample with 13.8% of GSC content and the one containing 22.5% of WNP can exhibit an impressive performance when used in buildings as ceiling.

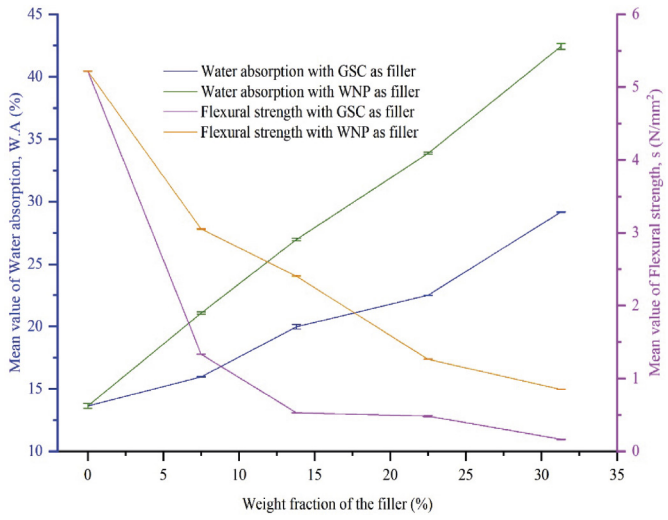

Fig. 3 Mean values of percentage of water absorption and flexural strength with filler proportion
3. ábra Vízfelvétel valamint hajlító szilárdság a kitöltőanyag mennyiség függvényében

4. Conclusions

Based on the experimental results obtained in this work, it was found that mixing P.O.P with either GSC or WNP resulted in new engineering materials with improved thermal properties. Also, it was observed that whether GSC or WNP is chosen for use as filler, its weight proportion can be adjusted to obtain a new material with P.O.P which can then be used as ceiling that is capable of exhibiting desirable physical, thermal and mechanical properties. Again, the new materials formed are cost-effective and environmentally-friendly. Therefore, since groundnut seed coat and waste newspapers are readily available as waste materials, using them as fillers in making P.O.P ceiling will enhance their utilization instead of allowing them to accumulate in the environment, help to reduce the cost of using P.O.P as ceiling in buildings and ensure better thermal insulation of buildings, and so on, thereby meeting the needs of end-users.

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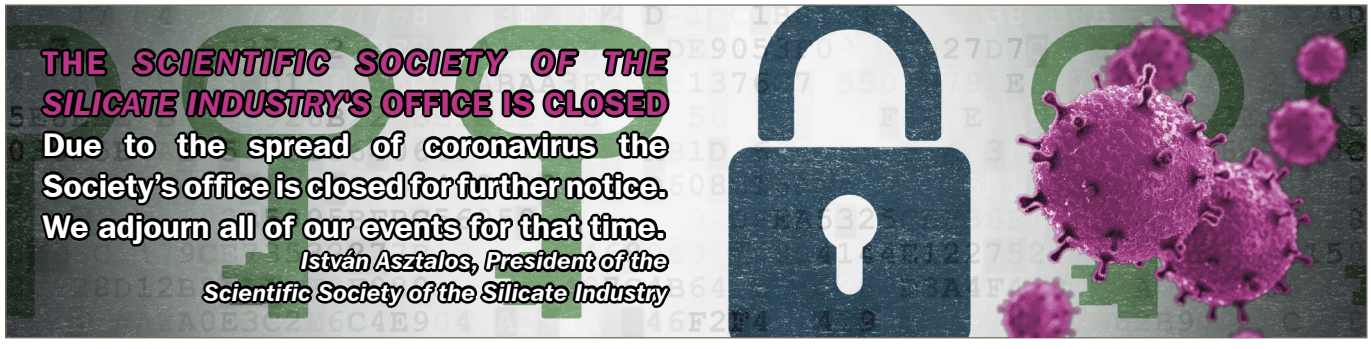

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