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Using Grinded Cane with Paraffin Wax in Interior Insulation of Buildings for Reducing Cooling Load

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Abstract

The present work aims to utilize a mixture of paraffin wax and grinded cane material as composite materials in building interior insulation. Two grinded cane material particle sizes (2 and 4 mm) were adopted. In addition, the effect of the mixing ratio of the grinded cane material (25, 50, and 75%) on enhancing mechanical, acoustic, and thermal performances was investigated. Moreover, two building ceiling models commonly seen in Baghdad were used to calculate the cooling load reduction rate. The outcomes of the experiments showed that filling the work specimens with the composite material of large particle sizes of grinded cane contributed to reducing the thermal cooling load of buildings, where the reduction rate in cooling load for the first ceiling model reached 1.17% when mixing 75% of grinded cane large particles, while, for the second ceiling model, the reduction rate reached 1.02% for the same mixing ratio. Mechanical performance significantly improved in a range of 285 to 433%, 168 to 521%, and 57 to 81.5%, respectively, in both tensile, impact and flexural tests. Moreover, increasing the mixing ratio and the particle size of the grinded cane material offers superior mechanical properties and better acoustic performance, where the noise levels were reduced by a range of 4 to 7.5%.

Keywords: Composite materials; Cooling load; Heat transfer; Interior insulations; Phase change materials

1. Introduction

In the last century, many insulation materials appeared in the building construction sector, such as plastic, wood, ceramic, etc. [1]. However, composite materials are popular in this field. Generally, composite materials are manufactured from two or more raw materials to produce a new material with superior characteristics to the original raw materials [2]-[4]. Many researchers are interested in utilizing different raw materials in buildings' insulations; some of them use inorganic raw materials, such as Ali et al. [5], who used unsaturated polyester resin with inorganic materials to enhance the mechanical properties (tensile strength, bending strength, tensile modulus, and bending modulus) by about 69.78%, 56.75%, 34.19%, and 40%, respectively. Others used organic raw materials that have an eco-friendly nature; for example, Hadi and Fadhil [6] used a composite of epoxy resin with a powder of Pistachio shells, and they revealed that mixing 5 to 7 percent of Pistachio shells' powder with the epoxy enhanced the mechanical performance of the composite material, while, raising the weight fraction of the Pistachio shells' powder led to the reverse result. Brouard et al. [7] studied the characteristics of a mixture of sunflower, straw, and clay, and they improved the thermomechanical characteristics to more comprehensive ranges. Saad et al. [8] investigated the usage of sago palm fibers with epoxy, and they found that the new composite material having 40 percent sago palm fibers presented the best mechanical performance. Abdullah et al. [9] proposed a composite material consisting of polymethyl methacrylate and eggshell powder, and they revealed that increasing the weight fraction of eggshell powder led to enhancing the flexural property and decreasing the wear property. Pachla et al. [10] studied the thermomechanical characteristics of a mixture of husk and rice straw, and they showed that using 15 percent of rice straw improved the thermal conductivity of the new composite material. Lou et al. [11] mixed epoxy resin with particles of corn stalk to make a new composite material. The researchers found that the best mechanical performance was using 20 percent corn stalk particles in the composite material. Malti et al. [12] proposed a mixture of polystyrene with date palm to reinforce wood-plastic composite material. The researchers revealed that the maximum mechanical performance could be achieved by utilizing the fibers of date palms at 75 %. In general, insulating materials are a barrier to reducing thermal losses in buildings, either from the inside to the outside or inversely. In contrast, phase change materials work to increase the thermal energy of the building by storing this energy, thereby providing passive cooling and heating techniques for the building. The influence of utilizing phase change materials in the building construction sector has been investigated in plenty of research, some of which focused on incorporating phase change materials into buildings' floors and ceilings [13], and others focused on using phase change materials within buildings' walls [14]-[16].

Moreover, the effect of internal conditions such as freezing or melting point and latent heat of fusion and external conditions like building design and climates on phase change materials performance were also investigated [17]-[19]. It is worth mentioning that using phase change materials with organic materials as bio-composite insulations contributes to reducing carbon dioxide emissions and, consequently, creating a healthy environment. However, selecting a suitable organic material to mix with phase change materials to get bio-composite insulation with superior characteristics is a complicated and expensive process and still needs a lot of research. Therefore, the innovation of the present work is producing a low-cost bio-composite material by combining a phase-change material (paraffin wax) with an organic material (grinded cane) that can be available in the local market and studying the feasibility of using the proposed material as interior insulation for buildings. The objective of the present work was achieved by evaluating the acoustic, mechanical, and thermal performances of the proposed composite material.

2. Experimental Procedure

2.1. Materials and Specimens Preparation

Paraffin wax was used as the raw material for the proposed composite material. Table 1 lists the properties of the used paraffin wax.

Table 1. Paraffin wax properties [20].

Property	Value
Melting temperature	44 ^{0}C
Specific heat	2000 J/ kg. ^{0}K
Density of liquid phase	770 kg/m^3
Density of solid phase	880 kg/m^3
Latent heat	255 KJ/kg
Thermal conductivity for liquid and solid phases	0.15 W/m. ^{0}K

Cane material was also used as the raw material for creating the proposed composite material. Cane was grinded using a manual grinder and sifted via sieves into particles with large sizes (4 mm) and small sizes (2 mm), as shown in Fig. 1.

(a) Grinded cane material

(b) Sieves used for the sifting process.

Figure 1. The grinded cane material and sieves used for sifting (a) Grinded cane material, (b) Sieves used for the sifting process.

The new composite material was made by well-mixing the melted paraffin wax with a grinded cane using an electric mixer, as shown in Fig. 2.

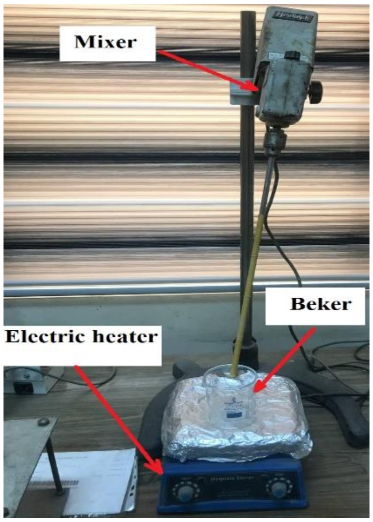


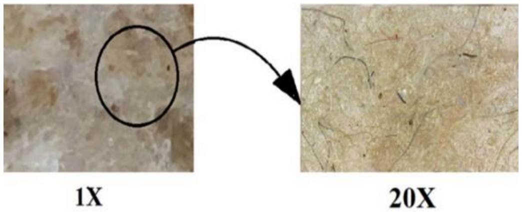
Figure 2. Instruments used in preparing the new composite material.

Three selective mixing ratios were used depending on changing the relative volume fractions, as shown in Table 2 [21].

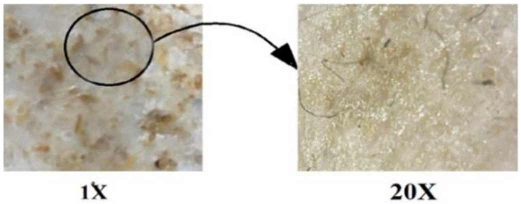
Table 2. Mixing ratios of composite material.

Specimen No.	Size of grinded cane particle	Cane ratio	Paraffin ratio
Specimen-1	4 mm	25%	75%
Specimen-2	4 mm	50%	50%
Specimen-3	4 mm	75%	25%
Specimen-4	2 mm	25%	75%
Specimen-5	2 mm	50%	50%
Specimen-6	2 mm	75%	25%

Enlarged photographs of the new composite material mixture were taken to check its homogeneity, as shown in Fig. 3.



(a) Grinded cane particle size=2mm



(b) Grinded cane particle size=4mm

Figure 3. Enlarged photographs of the mixture of paraffin wax with the grinded cane (a) Grinded cane particle size=2mm, (b) Grinded cane particle size=4 mm.

Polyvinyl Chloride panels (PVC wall panels) with a thickness of 7 mm were used as raw material for making the work specimens. The reason for selecting this type of panel is the everyday use of these panels in interior packaging for buildings and their availability in the local market at low prices. The work specimens were prepared by cutting the PVC panel according to the shapes and dimensions required for each test, then filling them with paraffin wax and grinded cane material. Seven specimens were prepared for each test; six were filled with the composite material, and one was empty for comparison, as shown in Fig. 4. The specifications and dimensions of specimens are listed in Table 3.

(a) Specimens used for thermal and mechanical performance tests.

(b) Specimens used for acoustical performance tests

Figure 4. Work specimens (a) Specimens used for thermal and mechanical performance tests, (b) Specimens used for acoustical performance tests.

Table 3. Specifications and dimensions of specimens.

Testing type	Dimensions	Standard specifications
Thermal conductivity	L= 40mm. W= 40mm. H = 7mm.	ASTM-D150
Thermal conductivity	D = 40mm. H = 7mm.	ASTM-D150
Tensile	L= 180mm. W= 35mm. H =7 mm.	ASTM-D638
Flexural	L= 100 mm. W= 8mm. H =7 mm.	ASTM-D790
Impact	L=45 mm. W= 8mm. H =7 mm.	ISO-179
Noise Level	L=240 mm. W= 240mm. H = 7mm.	ISO9614-1

2.2. Work Specimens' Tests

The thermal performance test measured thermal conductivity using a hot disc analyzer. The laboratory device used in the test is shown in Fig. 5. The test outcomes are listed in Table 4.

(a) Hot disc analyzer (b) Enlarged image of sensor

Figure 5. Hot disc analyzer device (a) Hot disc analyzer, (b) Enlarged sensor image.

Table 4. Outcomes of the thermal performance test.

Specimen No.	Thermal conductivity (W/m.^{0}C)
Specimen-1	0.47403132
Specimen-2	0.46900534
Specimen-3	0.44895473
Specimen-4	0.57859156
Specimen-5	0.50067545
Specimen-6	0.46904425

There are different types of mechanical property tests, but the important ones performed in this work are Tensile, flexural, and impact tests. These tests are essential to determine the work materials' capability to withstand external influences, such as compression, tension, shocks, and overloads. Table 5 includes details of the laboratory devices used to perform the mechanical performance tests and the testing rates.

Table 5. Details of mechanical test devices.

Test type	Device type	Max. load
Flexural & Tensile	JIANQIAO testing equipment	20 KN
Impact	Charpy Pendulum Impact Tester	45 J

Moreover, the tests' outcomes are listed in Table 6, and the specimens' shape after testing is shown in Fig. 6.

Table 6. Tests' outcomes for mechanical properties.

No.	Tensile test (MPa)	Impact test (KJ/m^2)	Flexural test (MPa)
1	12.144	2.749	10.074
2	13.061	3.276	10.141
3	13.796	6.3601	10.296
4	9.955	2.516	8.955
5	10.782	2.842	9.782
6	11.049	3.280	9.849

Figure 6. Work specimens after testing.

The acoustic performance test (noise or sound level) was done by using (ASTM E-336) instruments that consisted of an insulated chamber, a sound wavemeter with a range of 30–130 dB, a sound wave generator (UNIT 092812), a sound amplifier (TNG, Type: AV 298), and a speaker. The frequency range applied in all tests was between 0 and 4000 Hz because it is commonly used in estimating acoustics performance in the building construction field [22]. The laboratory instruments and the tests' outcomes are shown in Fig. 7 and Table 7, respectively.

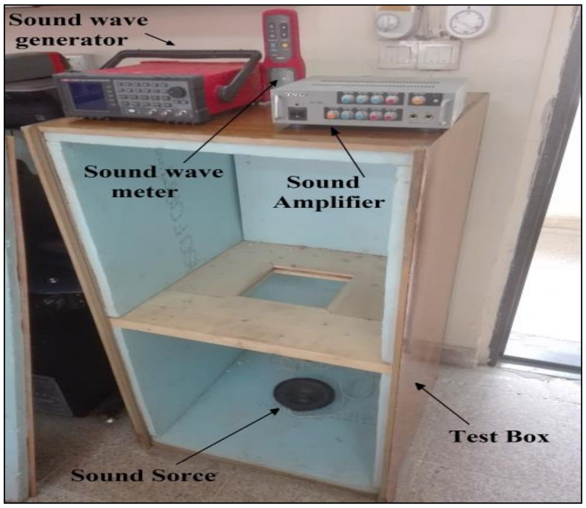
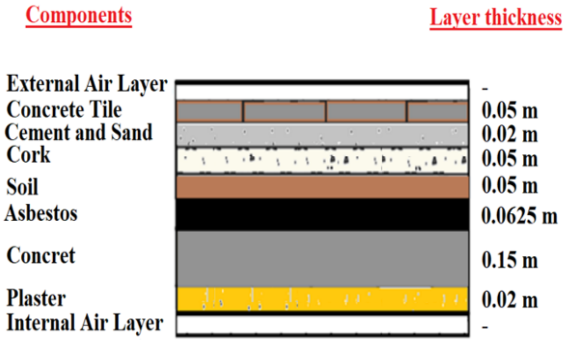


Figure 7. (ASTM E-336) instruments.

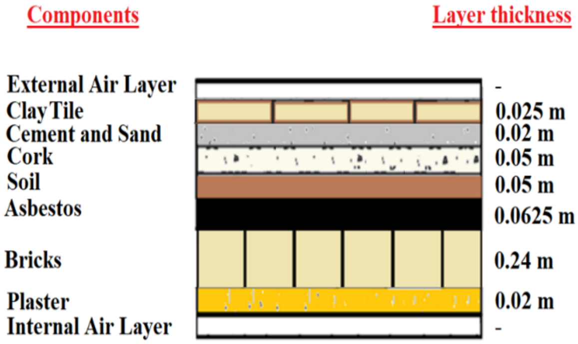
Table 7. Tests' outcomes for acoustical properties (noise level in dB)

Frequency (Hz)	Specimen type						
	Empty panel	**No.1**	**No.2**	**No.3**	**No.4**	**No.5**	**No.6**
100	94.5	88.7	87.8	87.2	90.1	89	88.4
200	94.6	88.8	87.9	87.3	90.2	89.1	88.5
300	94.7	88.8	88.1	87.5	90.3	89.1	88.5
400	94.8	88.9	88.2	87.6	90.3	89.2	88.6
500	94.9	89	88.5	87.8	90.4	89.4	88.7
600	94.9	89.1	88.5	87.8	90.5	89.5	88.8
700	95	89.2	88.5	87.9	90.6	89.4	88.8
800	95.1	89.2	88.8	88.2	90.6	89.4	88.8
900	95.2	89.3	88.9	88.3	90.7	89.5	88.9
1000	95.3	89.4	88.9	88.4	90.8	89.5	89
2000	96	89.8	89.3	88.7	91.1	90.8	90.2
3000	96.1	89.8	89.5	88.8	91.2	91	90.3
4000	96.2	89.9	89.4	88.8	91.3	91	90.4

The study, as shown in Fig. 8, also covered two models of building ceilings that are common in Baghdad to calculate the percentage reduction in cooling loads that has been calculated using the properties of the samples only.



(a) First Model.



(b) Second Model.

Figure 8. Specifications of Ceiling Models (a) First Model, (b) Second Model.

The first model comprised concrete with concrete tiles as essential components; the second included brick and clay tiles. Table 8 lists the details of all the elements of the two models.

Table 8. Details of ceiling Models' components.

Components	Thickness (m)	Thermal conductivity (W/m.°K)
External & internal air layers	-	-
Concrete tile	0.05	1.785
A mixture of cement and sand	0.02	0.721
Cork	0.05	0.045
Soil	0.05	0.788
Asbestos	0.0625	0.115
Concrete	0.15	1.775
Plaster	0.02	0.81
Briks	0.24	0.72
Clay tile	0.025	0.49

The overall heat transfer coefficient uc can be calculated based on the thermal resistances of the ceiling's components based on the thermal conductivity values used from tables 4 and 8, and the following equation can represent this coefficient [21]:

$$u_c = 1/\left({}^{1}/_{f_{in}} + {}^{x_1}/_{k_1} + {}^{x_2}/_{k_2} + {}^{x_3}/_{k_3} + \cdots + {}^{x_n}/_{k_n} + {}^{1}/_{f_{out}}\right) \tag{1}$$

The cooling load temperature difference method (*CLTDc*) was selected to calculate the cooling load of ceiling models before and after adding the secondary roofs. A computational program has been built to perform the calculations based on the following equations [23]:

$$Cooling\ load_c = u_c . A_c . CLTD_c \tag{2}$$

$$Cooling\ load_r = \{(cooling\ load_{without} - cooling\ load_{with})/cooling\ load_{without}\} \times 100\% \tag{3}$$

The (CLTDc) is specified based on the external design temperature and its daily change rate, where the daily change rate, according to references [24], [25], can be divided into three groups as follows:

A- Little daily change rate, where the difference is less than 9 °C.

b- Medium daily change rate, where the difference is ranged from 9 to 14 °C.

c- High daily change rate, where the difference exceeds 14 °C.

3. Results and Discussion

3.1. Acoustical Performance

Fig. 9 presents the acoustic performance of the present work specimens. Adding the suggested composite material to PVC wall packaging panels enhances acoustical performance by lowering noise levels by 4 to 7.5%. This is explained by the fact that the material made from grinded cane contains cellulose fibers, which dampen sound waves as they travel through the material's structure [22]. Furthermore, increasing the proportion of grinded cane material reduces the noise level, thereby improving acoustic performance. This is mainly due to the increase in cellulose fibers. In addition, it can be observed that decreasing cane particles' size has a reverse effect on acoustic performance. This behavior can be attributed to the fact that the small particle size makes the material structure very tight due to lowering the porosity (i.e., lowering air volumes) inside the material structure. Thus, sound waves cannot easily pass through the material matrix and dissipate [26], [27].

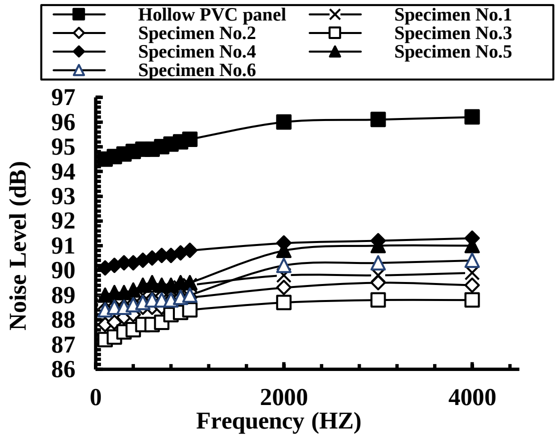
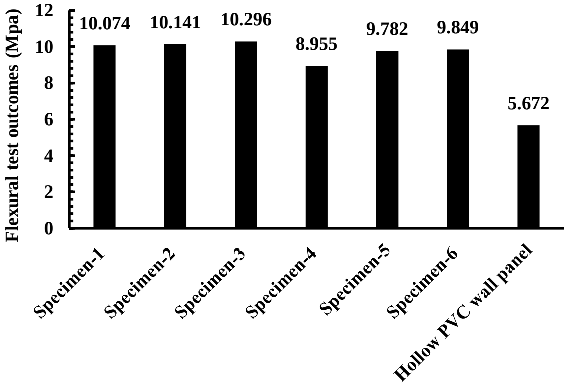


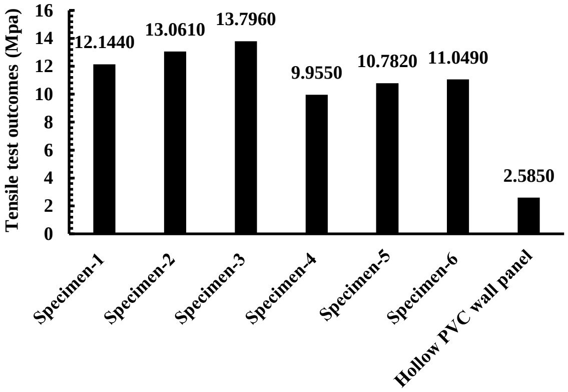
Figure 9. Acoustic performance.

3.2. Mechanical Performance

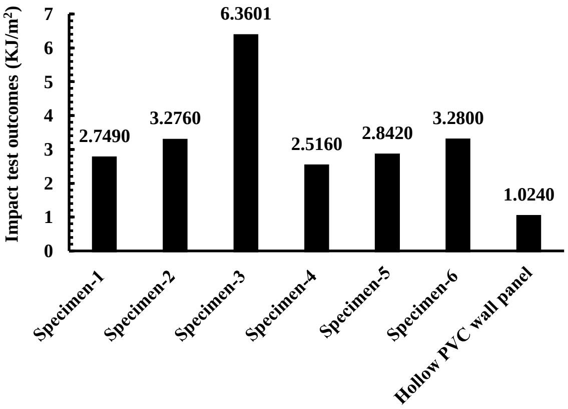
The mechanical performance, represented in flexural, tensile, and impact tests, is shown in Fig. 10. It is clear that using the proposed composite material within the PVC panels presents superior mechanical performance compared to the hollow PVC panels. This performance shows ascending behavior with rising grinded cane content. It was found that the specimens filled with composite material outperformed the hollow specimens by approximately 285 to 433% in the tensile test, 168 to 521% in the impact test, and 57 to 81.5% in the flexural test. This can be attributed to the presence of cellulose fibers in the grinded cane material that works on enhancing the adhesive between the composite layers and making them more cohesive, hence increasing the ability to withstand harmful externalities that may cause damage, for example, shocks, overloads, and compression-tension [28]. Furthermore, specimens that contain a small particle size of grinded cane material offer better mechanical performance than those with a large particle size. This is due to low porosity; hence, the specimen layers will be closer and more solid [29].



(a) Flexural strength



(b) Tensile strength



(c) Impact strength

Figure 10. Mechanical performance tests' outcomes are (a) flexural strength, (b) tensile strength, and (c) impact strength.

3.3. Thermal Performance

The reduction in cooling load for the two ceiling models is presented in Fig. 11. It can be seen from these Figures that the decrease in the cooling load increases with increasing both the size and the content of the grinded cane material, where the reduction rates, depending on the specimen used, ranged between 0.9% and 1.17% in the first ceiling model and between 0.7% and 1.02% in the second ceiling model. This behavior can be attributable to the fact that the specimens filled with a grinded cane material of large particle size (4 mm) have lower thermal conductivity than other specimens; hence, increasing the grinded cane particle's size as well as its content leads to an increase in thermal resistance and, consequently, an increase in the cooling load reduction rate as well.

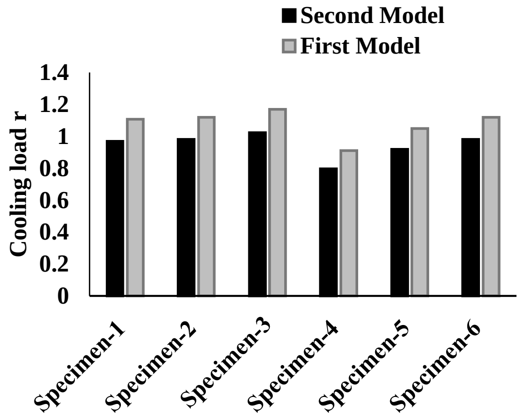


Figure 11. Cooling load reduction for the two models.

4. Conclusion

Based on Experiments outcomes, the PVC panels that are filled with the proposed composite materials presented superior mechanical performance over the hollow PVC panels by approximately 285 to 433% in the tensile test, by approximately 168 to 521% in the impact test, and by approximately 57 to 81.5% in the flexural test. This significant enhancement in mechanical properties is related to increasing the grinded cane material ratio and the grain particle's size. Moreover, the PVC panels that are filled with the proposed composite materials offer higher acoustical insulation performance by about 4 to 7.5% than hollow PVC panels—in addition, increasing the grinded cane material content improved thermal insulation. Finally, depending on the experimental outcomes, it can be demonstrated that the proposed composite materials can be used for acoustic insulation applications in buildings. Increasing the grinded cane material's size and content makes it suitable for thermal insulation applications.

Acknowledgments

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Conflict of interest

The author declares that there are no conflicts of interest regarding the publication of this manuscript.

Abbreviations

Cooling load$_c$	Cooling load of the ceiling
Cooling load$_r$	Reduction rate in cooling load
f_{in}, f_{out}	Air's thermal resistances
H	Hight
k_1, k_2, k3, k_n	Thermal conductivity
L	Length
W	Width
x_1, x_2, x_3, x_n	Ceiling layers' thicknesses

Author Contribution

The author proposed the research problem, developed the research methodology, performed the computations, wrote the findings, discussed the results, and contributed to the final manuscript.

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