

# Mechanical Properties of Coconut Shell Powder Reinforced PVC Composites in Automotive Applications

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## ABSTRACT

*Coconut shell powder (CSP) (which is used in reinforced Polyvinyl Chloride (PVC)) is one of the possible candidates of materials suitable as automotive components; however, appropriate tests need to be done to evaluate whether it meets all requirements. CSP-reinforced composites are made with PVC matrix within the range of 0 - 20 phr and the effect of the reinforcement of the natural fibres on the mechanical behaviour of PVC has been analysed. Both Universal Tensile Machines and Impact Testing Machines are used to determine the mechanical properties of CSP/PVC composites (such as the tensile, flexural and impact strength as well as its modulus of elasticity). The experimental results indicated that tensile strength, impact strength and flexural strength improved by 42%, 25% and 23%, respectively, when compared to the pure system.*

**Keywords:** *Coconut Shell Powder (CSP), polyvinyl chloride (PVC), mechanical properties, automotive, polymer composites*

## Introduction

Over the last three decades, polymers, ceramics and composite materials have become recognised as the predominant developing materials. The amount of usage of composite materials has become relentless, entering and vanquishing new markets tenaciously. Currently, composite materials constitute a critical extent of the built materials business, ranging from ordinary items to advanced corner applications [1]. The use of polymer in the automotive industry during the past century has been quite extensive; historically, one might say there had been plastics in automobiles for almost as long as polymer. Since 1970, studies have shown that polymer use consists of 6 % from an average 1100 kg vehicle weight. A significant amount of polymer such as PVC [2], High Density Polyethylene (HDPE) [3], Polylactic Acid (PLA) [4] and Polystyrene (PS) [5] is used in typical vehicles for the various components.

The objective of the automotive industries is to manufacture automotive components having the following qualities: low fuel consumption; convenience; safety; environmentally-friendly qualities and maximum efficiency [6]. Natural fibre reinforced polymer is a material that offers benefits such as: being environmentally-friendly; easily renewable; low-cost; reduced weight; flexibility and biodegradability [7, 8]. Fibre composites have become in high demand in recent years in the automotive industry for internal and external component uses. For automotive components, the interior trim consists mostly of: polymer (including PVC); Acrylonitrile Butadiene Styrene (ABS); Polyethylene Terephthalate (PET); etc. These comprise 20 kg of the average car weight [9]. Nowadays, the PVC demand in automotive industries is at peak level; for example, it is being used as: dashboards; carpets; door panels; armrests; grips; interior seals; sun visors; seat coverings; luggage compartment; cable insulation; moulded plugs; air intake piping; etc. The roles of natural fibre composites are to utilize the fibre as reinforcements in matrix resin. To optimize vehicle performance, the reduction of vehicle mass (or having light-weighting) is compulsory.

Natural fibre contains high cellulosic attributes such as sisal, henequen, coconut fibre (*Cocos Nucifera*), palm, jute, bamboo, and paper in their characteristic condition. In addition, it contains a few waste cellulosic items, for example: shell flour; oil pump empty fruit bunch [10, 11]; wood flour; banana [12] and pulp as reinforcement materials that are used in thermoset and thermoplastic resins [2, 13-16]. Towards the start of the 20<sup>th</sup> century, phenyl-formaldehyde and melamine-formaldehyde resins compounded with paper or cotton were utilized for electric insulation which had already found applications in the automotive industry for almost five decades [17]. Coconut fibre was used to manufacture seat compartments together with polypropylene (PP) composites with wood flour [18] which appeared to act as a substitute for wood in deck boards [17]. Surface modification by using Silane Coupling

Agent aims to enhance the interfacial adhesion between the CSP and PVC matrix which improves the mechanical properties such as tensile strength, modulus, and flexural strength [19]. For example, Mercedes-Benz uses coconut fibre in the seat backrest while Honda uses wood fibre as their floor area parts [20].

One of the outstanding properties of PVC is that it can withstand chemical harshness in terms of the corrosion aspect. Further, it also provides strength and more rigidity compared to other thermoplastics [21]. There are several safety issues regarding PVC. For instance, there is an environmental safety issue which arises when vinyl chloride is used as the monomer of PVC. This causes serious health problems; for example, it may be a carcinogen [22]. Natural fibre PVC composites mixed with CSP present another alternative for an “ecologically–friendly substance” as it can reduce disadvantages while conserving its advantages.

The purpose of this study is to improve PVC resin in use in the automotive industry by adding CSP as a natural fibre reinforced composite. Besides having the ability to enhance the strength of PVC, it is also environmentally-friendly.

## **Materials and experimental procedures**

### **Materials and sample preparation**

Thermoplastic PVC grade MH-66 was supplied by Industrial Resin Malaysia (IRM) Sdn. Bhd. and CSP was obtained from DRPTS Manufacturing Sdn. Bhd. while Silane-Coupling Agent was acquired from Sigma Aldrich. A sieving machine was used to achieve the required size of the powder (which is 300  $\mu\text{m}$ ) in order to ensure a good mixing and better dispersion during the addition of PVC. The CSP/PVC composites were prepared by mixing PVC with CSP by using the different composition of the natural fibre. Table 1 shows the composition of PVC.

Table 1: Composition of PVC blending

<b>Materials</b>	<b>Composition (phr)</b>
Poly (vinyl chloride)	100
Calcium Stearate (CaSt)	0.5
Acrylic polymer (PA-Acr)	4.0
Titanium Oxide (TiO <sub>2</sub> )	4.0
Tin (Sn)	2.0
Stearic Acid (Hst)	1.5

The chemical composition of CSP consists of: Lignin (30.2%); Pentosans (26.9%); Cellulose (26.3%); Moisture (9.5%); Solvent Extractives (4.7%);

Uronic Anhydrides (2.1%); and Ash (0.3%). Different compositions of CSP were used in this research from 0, 5, 10, 15, and 20 phr. The reason for choosing this set of values is to obtain a suitable consistency and the best result for this experiment [24].

A diluted solution of methanol/water (4:1) and 1wt% silane weight proportion was prepared and thoroughly mixed by stirrer for one hour. 500g of CSP were mixed into the solution and kept stirred for two hours. Vacuum filtration was used to eliminate water from CSP. The treated CSP were dried in a fume cupboard for two days before mixing with PVC resin and other ingredients of composites. PVC resin and treated CSP were dry-blended using a high speed blender for 10 minutes with a speed of 40 rpm. Dry blended mixtures of different formulations were melted by using two roll mill machines at 180 °C and rotor speed of 80 rpm. The method used was “cut and fold” in order to become a sheet of CSP/PVC composites.

For the compression process, a layer of wax was applied to the mould to ensure that the specimen can be easily taken out of the mould. The sheet of CSP/PVC composites were cut into small pieces and poured into the mould according to the tests (see Figures 1 and 2). A dumbbell-shaped mould was used for the tensile test specimen. The dimension of the specimen is shown in Table 2.

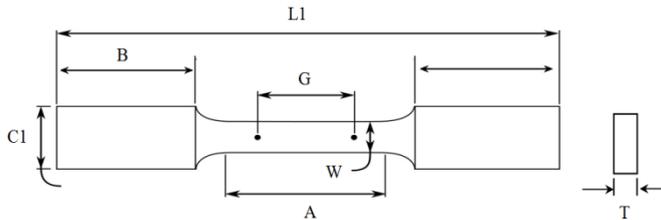


Figure 1: Diagram of tensile test specimen

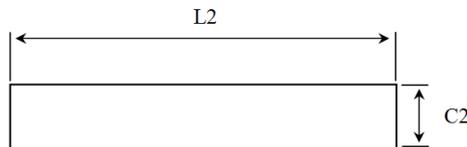


Figure 2: Diagram of flexural test specimen

Table 2: Dimension of test specimen

Parameter	Standard dimension (mm)
G - Gauge length	50 ± 0.25
W - Width	13 ± 0.5
B – Length of grip section	50 ± 5
A – Length of reduced section	57 ± 0.5
T - Thickness	7 ± 0.4
T1 – Thickness flexural	3.2
L1 – Overall length	165
L2 – Overall length	127
C1 – Width of grip section	22 ± 3
C2 – Width of grip section	12.7

The plates were covered by two thin polyethylene films on both sides of the mould. The compression process was carried out by preheating the sample at 200°C for four (4) minutes; followed by compression for five (5) minutes. Cooling was conducted for 10 minutes at room temperature under sustained pressure before being removed from the machine.

### Physical properties

Density of samples of known weight and rate of water absorption were measured using Equations (1) and (2) respectively. The tests were carried out by using five samples and the averages were calculated.

$$\rho = \frac{m}{v} \quad (1)$$

Where  $\rho$  is the density,  $m$  is the mass of sample and  $v$  is the volume of sample

$$\% \text{ weight sample} = \frac{\text{final weight} - \text{initial weight}}{\text{initial weight}} \times 100 \quad (2)$$

For determination of water absorption, the dried samples were weighed and put in a beaker with water for six days and reweighed after a one day interval.

### Mechanical properties

An Instron 5567 Universal Testing Machine equipped with 30 kN load cell, a mechanical clamping device and an extensometer were used to measure the tensile strength and flexural strength of the samples. The measure of tensile

stress was carried out according to ASTM D638 standard with a dumbbell shape and was determined according to the Equation (3) while Modulus of elasticity was determined by using Equation (4).

$$\sigma_t = \frac{F}{A} \quad (3)$$

Where  $\sigma_t$  is the tensile stress,  $F$  is the force at the fracture point and  $A$  is the cross sectional area.

$$E = \frac{\sigma_t}{\epsilon} \quad (4)$$

Where  $E$  is Young Modulus of Elasticity and  $\epsilon$  is the strain. A flexural stress test was carried out according to the ASTM D790 standard and was determined according to Equation (5).

$$\sigma_f = \frac{3FL}{2bd^2} \quad (5)$$

where  $\sigma_f$  is the flexural stress,  $L$  is the length of support span (mm),  $b$  is the width of specimen (mm) and  $d$  is the thickness of specimen (mm).

Another test known as the impact test was also carried out according to the ASTM D256 standard. The objective is to measure the relative susceptibility of the composites to the pendulum type impact load. A sample with a size 63.5 x 12.7 x 3.5 mm and V notch were prepared in the middle of the samples. Equation (6) was used to calculate impact strength where  $I$  is impact strength and  $J$  indicates the energy absorbed. For each of the tests, five samples were tested and presented as the average of the tested samples.

$$I = \frac{J}{A} \left( \frac{kJ}{m^2} \right) \quad (6)$$

## Result and Discussion

### Density and water absorption

Figure 3 shows that an absorption rate of 4.2% was gained from the 20 phr of CSP composition compared to the pure PVC which is only a rate of 1%. It shows that water absorption increases with an escalation in fibre contents. This phenomenon is due to the characteristic of hydrophobic of PVC and the specific quality of hydrophilic nature from the natural fibre having a better interfacial area between fibre and matrix [23]

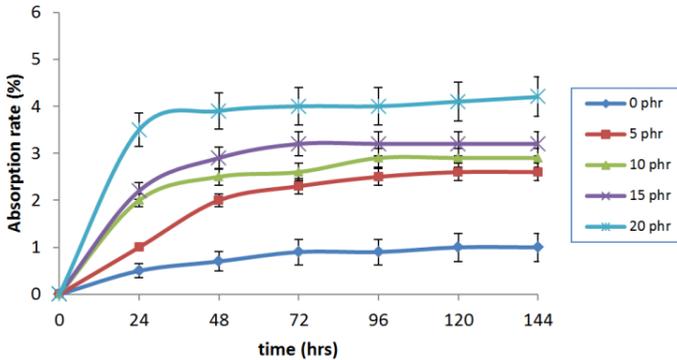


Figure 3: Effect of CSP on the rate of absorption of PVC composites.

Figure 4 shows that a decrease in density was due to the effect of less porosity. An increase in water absorption causes a lower mass of composites. This shows that the hydrophobic character of the PVC is very good, especially in the interior part of an automobile. The main advantage of polymer is that it is lightweight and this is good from the point of view of the automotive industry. Besides reducing the overall weight of automotive vehicles, it also reduces fuel consumption to a legislated limit [24].

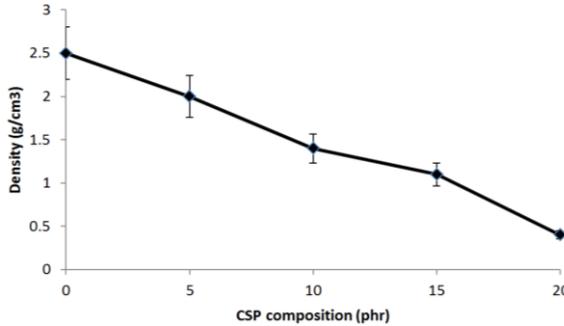


Figure 4: Effect of CSP content on density of PVC composites

### Tensile and impact properties

The tensile strength of pure PVC was  $47 \times 10^3 \text{ kN/m}^2$ , as shown in Figure 5. As the CSP level increases, the tensile strength improved except for the first loading, due to insufficient fibre to reinforce the matrix of the composites and also less interfacial adhesion [25]. With the CSP loading levels increased from 5 to 20 %, the tensile strength increased accordingly from  $47 \times 10^3$  to  $67 \times 10^3 \text{ kN/m}^2$ . Cellulose levels are very important for the tensile strength. As a result

of its fibrous structure and high hydrogen, it has high tensile strength. Hence, the higher the cellulose content, the higher the tensile strength obtained [26].

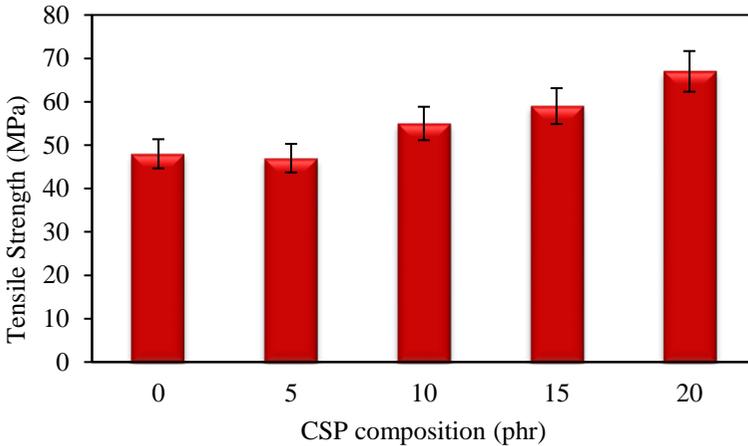


Figure 5: Effect of CSP on the tensile strength of PVC composites.

The Modulus of Elasticity of pure PVC is  $3 \times 10^6$  kN/m<sup>2</sup>, as shown in Figure 6. For CSP/PVC composites, the modulus increased to 3.5, 3.9, 4.5, and 5 GPa at the loading levels of 5, 10, 15, 20 phr CSP, respectively. It shows that the addition of CSP improves the Modulus of Elasticity of composites by  $2 \times 10^6$  kN/m<sup>2</sup>. This phenomenon is due to the stiffness of the reinforcement which intensifies with an increase in fibre content.

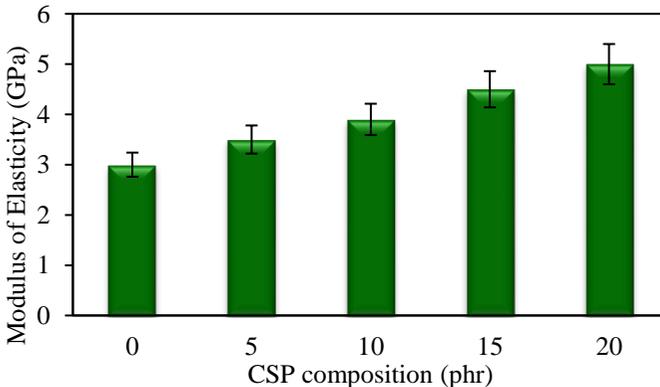


Figure 6: Effect of CSP on the modulus of elasticity PVC composites.

The variation of impact strength is shown in Figure 7. Impact strength of the composites slightly increases with a corresponding increase of CSP in the PVC. The highest is  $0.65 \text{ kJ/m}^2$  for 15 and 20 phr CSP compared to the pure PVC which is  $0.52 \text{ kJ/m}^2$ . It indicates the ability of this composite to cope with applied stress over a large volume at the base of the notch. Good dispersion of fibre contributes high strength to withstand crack propagation. Silane-treated CSP showed greater improvement in CSP/PVC composites. The fibre plays an important role in impact strength; it resists crack propagation and acts as a load transfer medium. Improvement in impact strength of the composites is due to an increment in fibre content. The applied stress is transferred effectively due to effective interfacial bonding strength.

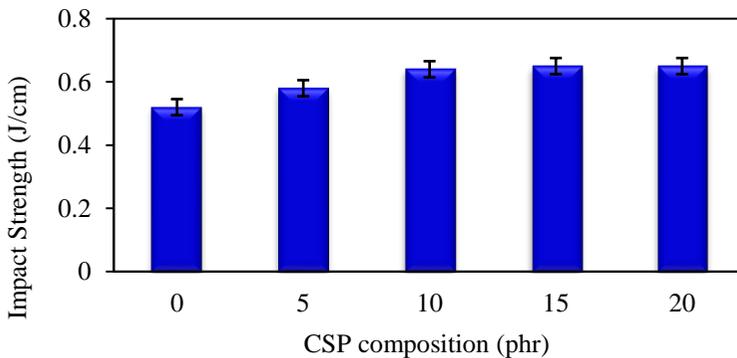


Figure 7: Effect of CSP on the impact strength of PVC composites.

### Flexural properties

For flexural strength, pure PVC is  $84 \times 10^3 \text{ kN/m}^2$ . As CSP levels increase, the flexural strength is improved. The addition of CSP (5 phr) to CSP/PVC composites resulted in a slightly lower flexural strength than the pure PVC of  $82 \times 10^3 \text{ kN/m}^2$  (see Figure 8). At 5 phr CSP loading, the flexural strength slightly decreases as the CSP level increases. The flexural strength increased to  $88 \times 10^3$ ,  $94 \times 10^3$ , and  $104 \times 10^3 \text{ kN/m}^2$  at the loading levels of 10, 15, and 20 phr CSP respectively. This can be explained by the improvement of phase compatibility between the fibre and the polymer surface after silane modification by reducing the hydroxyl group [27]. As a result, the composite ability to resist deformation under load will improve.

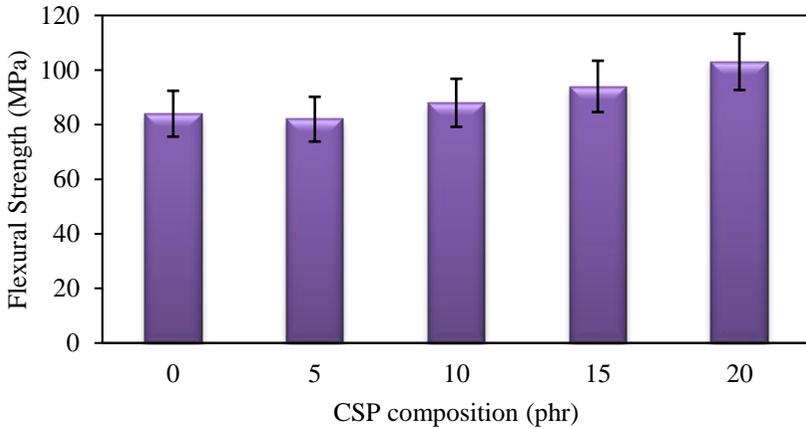


Figure 8: Effect of CSP on the flexural strength of PVC composites.

## Conclusion

The effects of CSP on the mechanical properties of CSP/PVC composites have been studied. The results show that a maximum  $67 \times 10^3 \text{ kN/m}^2$  tensile strength of CSP/PVC composites were obtained or an increase of 42% improvement while the modulus is  $5 \times 10^6 \text{ kN/m}^2$  or has a 66% improvement. The maximum flexural strength of CSP/PVC composites is obtained by loading levels in 20 phr of CSP. The result obtained was  $104 \times 10^3 \text{ kN/m}^2$  or 25% improvement and, for impact strength, 23% improvement was obtained. The result shows that the tensile strength, modulus of elasticity, flexural strength and impact strength of CSP/PVC composites were improved compared to the pure PVC.

For automotive interior parts such as seat covers and dashboards, the use of these composites can reduce the cost of PVC as well as improve the overall strength of the parts. In terms of weight, CSP can reduce the overall weight of these parts through lowering of the composite density, and hence can improve the fuel efficiency. For engine parts, these composites can replace steel (even PVC material in the air intake piping system) because of its advantages. By using these composites, it can reduce a cost of base polymer and also can decrease the effect of environmental issues concerning energy and carbon credits.

When referring to strength, this experiment shows that strength increases when the fibre content increases. Hence, in the automotive industry (especially in the production of polymer), parts such as bumpers or interior parts can be protected if an accident occurs compared to when using the pure PVC. In addition, it can reduce the virgin material but improve strength by the

addition of this fibre. Therefore, this composite ‘Coconut Shell Powder (CSP)’ is very useful to the automotive industry for reduction of cost and weight and, at the same time, improvement of PVC strength performance.

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