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DEVELOPMENT OF PAPER PULP FILLED CEMENTITIOUS COMPOSITES FOR FURNITURE AND FITTINGS APPLICATIONS

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Abstract: *The need for aesthetic, strong and environmentally beneficial composites for furniture and fittings was the thrust of this work. The research involves comparative study and analysis of the behavior of brown and white papers when they are mixed with different proportions of cement as binder. Waste papers from offices were sourced locally and were sorted into white and brown papers after which the papers were pulverized and made into slurry. The slurry obtained were compacted into flexural and compressive tests samples with the aid of compacting machine by applying a load of 20 KN for 5 minutes followed by drying at room temperature in the laboratory. Flexural, compressive and water absorption tests were carried out on the samples using universal testing machine and percentage weight different of immersed samples in water respectively. It was observed from the results that, white paper cement bonded samples possessed the best properties in all compared to brown paper cement bonded samples. The results showed that the mixture of 70 % white paper and 30 % cement possess the best combination of mechanical and physical properties and hence, the potential material for paper pulp composite in low cost furniture and fittings applications.*

Keywords: *waste paper, cement, paper pulp, composites, mechanical properties, water absorption*

INTRODUCTION

In the topical age, research and development is been focused on the use of naturally available raw materials as well as waste materials for engineering application. This was the case because; they not only occur in luxurious abundance in many parts of the world, but can also lead directly to energy savings, conservation of the world's most scarce resources and also protect humans and his environment. Natural and vegetative plants have thus a unique irreplaceable role in the ecological cycle. Throughout history, technological innovations have helped humankind improve their standards of living through impressive rapid developments and research. However, some technology also creates negative environmental impact. Therefore efforts are invested in making use of natural based biodegradable and sustainable material that exist in nature rather than create a new material [3].

Composite materials generally have properties such as lighter weights, ability to be tailored for optimum strength and stiffness, improved fatigue life, corrosion resistance, and reduced assembly or manufacturing costs due to fewer detail in parts and fasteners. Due to the excellent mechanical properties of composite materials, they have been widely used throughout the last four decades [4]. Composites are designed to display combination of the best properties of each of its constituents. Properties of composite are strongly dependent on the properties of their constituent materials, their distributions, and the interaction among them [5]. The composite properties may be the volume fraction sum of the properties of the constituents or the constituents may interact in a synergistic way resulting in improved or better properties. Apart from the nature of the constituent materials, the geometry of the reinforcement (shape, size and size distribution) influences the properties of the composite to a great extent. The concentration, distribution, and orientation of the reinforcement in the matrix also affect the properties of the composite. The interface has characteristics that are not depicted by any of the component in isolation. The interface is a bounding surface or zone where a discontinuity occurs, whether physical, mechanical or chemical. To obtain desirable properties in a composite, the applied load should be effectively transferred from the matrix to the fibres via the interface [6]. This means that the interface must be large and exhibit strong adhesion between fibres and matrix. Failure at the interface (called de-bonding) may or may not be desirable [4].

Wood, which serves as a major raw material for the production of paper consists of lignin, hemicellulose, cellulose and extractives. The percentage of lignin in the composition of paper wood is about 20-30%. During pulping, about 50% of the whole wood material and about 95% of the lignin are removed [7]. Paper is a wood based product without which modern civilization would not have evolved, and would not have been sustained and advanced. But paper itself, is a major product of wood pulp; i.e. pulp gives birth to paper, also pulp can be used for diverse purposes such as in the preparation of cellulose derivatives e.g. cellulose nitrate, cellulose acetate, regenerated cellulose etc. [1].

White papers are produced when bleaching operation took place as a result of the removal of lignin in the pulp from the pulp mill Lignin is a *complex chemical compound most commonly derived from wood, and an integral part of the secondary cell walls of plants. It is one of the most abundant organic polymers on earth, exceeded only by cellulose, employing 30% of non-fossil organic carbon [2] and constituting from a quarter to a third of the dry mass of wood.*

Through bleaching, the brightness is increased as the remaining lignin and other coloured substances are removed from the pulp. Bleaching also removes impurities from the pulp and improves the printability of paper produced [8]. As a result of the bleaching process and removal of lignin, the crystallinity of the structure of the paper material improves, thus enhancing the strength properties of the white paper material.

In modern buildings, furniture and fittings such as light weight tables and stools, portraits, flower vases and many more for low cost applications are the focus of this work. The aim was to transform readily available biodegradable materials that are regarded as waste into useful applications by manipulating them to develop strong and light weight low cost furniture and fittings materials.

MATERIALS AND EQUIPMENT USED

In this research work, the following materials and equipment were used for the production of the paper boards.

Materials and Equipment

Waste office papers (white), waste newsprint papers (brown), Portland cement and water.

The following major equipment were used for the research; milling machine from Forestry and Wood Technology Department, compaction machine from Metallurgical and Materials Engineering Department both at Federal University of Technology Akure, Ondo State, Nigeria, Testometric universal machine from Federal Institute of Industrial Research Oshodi (FIIRO) Lagos State, Nigeria.

Methods

» **Preparation of Paper Particles**

The papers to be pulverized were soaked in water for two weeks so as to ensure smooth grinding and, thus reduce the pulverizing time. The wet paper which has been soaked was poured into the grinding milling machine as shown in Figure 1.

Figure 1: *Paper pulp in slurry form during grinding operation*

During the grinding process, water was added to aid easy formation of slurry. The slurry allows even distribution of the papers that are being grinded within the machine. The pulverized paper was squeezed in order to remove the water and sun dried for 5 days to obtain particulate material.

» **Composites Development**

The composites were developed by forming the homogeneous pastes from the mixture of cement with white and brown papers slurry, respectively in predetermined proportions as shown in Table 1. Paper slurry was formed by blending 1 kg of the sun dried particulate paper with 8 litres of water followed by mixing in a bucket to form the slurry.

Table 1: *Mixing proportions of cement with white and brown papers*

Compositions/ Samples	Control	A	B	C	D	E	F	G	H
Paper in slurry (%)	100	95	90	85	80	75	70	65	60
Cement (%)	-	05	10	15	20	25	30	35	40

Each representative samples were produced by pouring the homogenous paste into the flexural and compressive moulds. Compression moulding machine was used to press the samples inside the mould at room temperature with a load of 20 KN for 5 minutes. The samples were de-moulded after compaction and allow drying at room temperature in the laboratory for 28 days as shown in Figure 2.

Figure 2: *Flexural and compressive samples of cement bonded white and brown paper boards*

Properties Test

» **Flexural Strength**

Flexural test was carried out by using Tensiometric Universal Testing Machine in accordance with ASTM D790. To carry out the test, the sample that has been shaped into the test piece dimensions of 150 × 50 × 30 mm was hooked on the grip, and the test commenced. As the specimen is stretched, the computer generates the required data and graphs. The test speed was 50.00 mm/min over a span of 100.00 mm.

» **Compressive Strength**

The compressive test was also carried out by using Tensiometric Universal Testing Machine in accordance with ASTM C 39

Cylindrical specimen was centered on the test machine and loaded to complete failure. Th loading rate on a hydraulic was maintained in a range of 20 to 50 psi/s (0.15 to 0.35 MP a/s). Afterwards, the type of break was recorded and the computer generates the required data and graph.

» ***Water Absorbtivity Test***

Water absorption test was carried out in accordance with ISO 175 using distilled water. This medium was chosen because the material is likely to encounter water in service. To carry out the test, clean plastic containers were procured into which 700 cm^3 of water was measured using measuring cylinder. The initial weight of each of the sample is taken using chemical weighing balance; FA2104A Model which is of high precision ± 0.0001 g accuracy before dropping inside the medium to be used and readings were taken every hour for seven hours. To take the readings, the samples were brought out, clean with white cloth and weighed. The data collected was used to determine the % water absorption using equation 1.

$$\%\,Water\ Absorption = \frac{Final\ Weight - Initial\ Weight}{Initial\ Weight} \times 100 \qquad (1)$$

RESULTS AND DISCUSSION

Response of the materials to bending properties

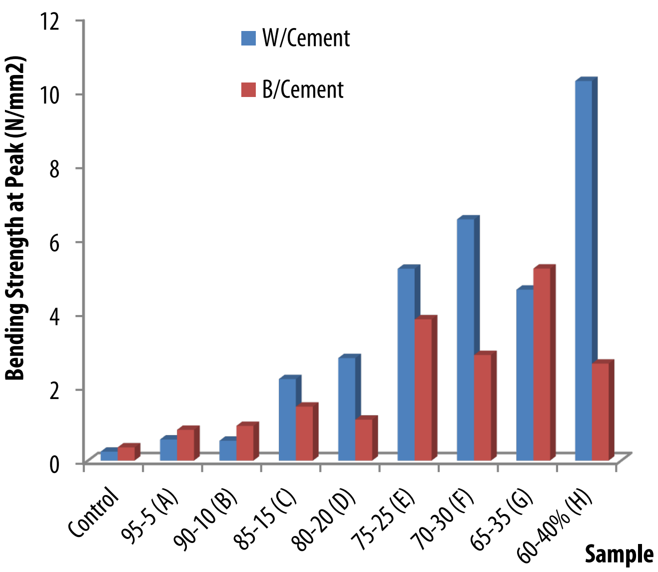

***Figure 3**: Plots of variation of Bending Strength at Peak with Samples*

The results of the variation of bending strength at peak were shown in Figure 3. From the results, it was observed that, the use of cement as binder for these paper pulps increases the bending strength of the developed composites more than the bonded paper without cement which serves as the control. Also, noticed was that, the strength of the developed composites tends to increase as the paper pulp content increases, particularly in the cement bonded white paper pulp composites.

The results revealed that white paper pulp bonded with cement gave the best output compared to brown paper pulp cement bonded. The best result was obtained when 60 wt % of the white paper pulp was blended with 40 wt % of cement with a bending strength value of 10.27 N/mm^2 followed by 70 wt % white paper pulp filled composite with values of 6.53 N/mm^2 and 65 wt % brown paper pulp filled cementitious composite with a value of 5.20 N/mm^2, respectively. Comparing these with the ordinarily bonded white and brown paper pulps strength with values of 0.24 and 0.36 N/mm^2, these has culminated to greater enhancement from both paper pulps, respectively. The improvement in the enhancement of the strength at peak for white paper pulp over brown ones which initially has better strength was due to the presence of lignin in the brown paper and the delignification that was achieved in white paper during bleaching. The presence of lignin in brown paper pulp prevents proper blending between the paper and cement during mixing, hence, the removal of lignin from the paper pulp through bleaching, the process for the production of white paper, aid proper blending of binders with the white paper pulp. This was possible because the binders will penetrate easily into the paper and thus the strength properties of the composite product made from white papers was greater than the ones made from brown papers.

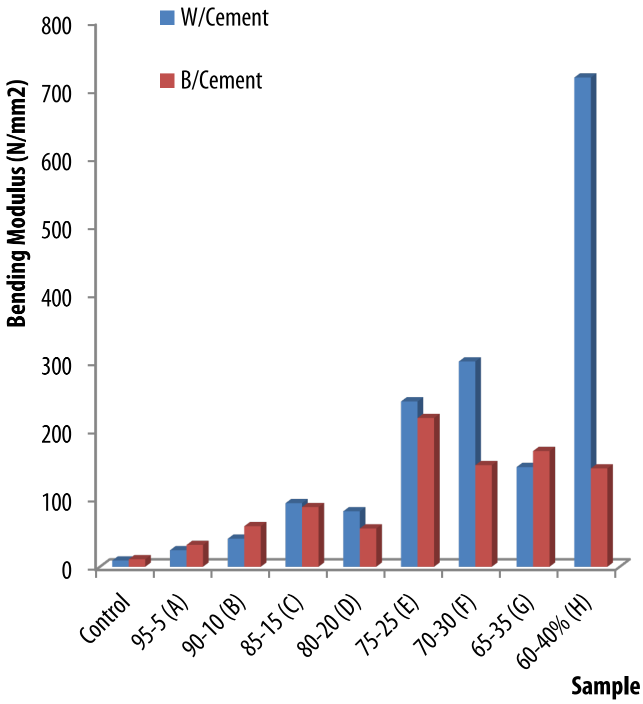

***Figure 4**: Plots of variation of Bending Modulus with Samples*

Figure 4 illustrates the response of the materials to bending modulus. From the results, similar trend to that of bending strength at peak was observed. At low weight fraction of between 5-20 wt % cement, bending modulus was observed to be low while at higher weight fraction of between 25-40 wt % cement content, bending modulus was observed to be high. It follows that the strength and stiffness of the developed composites were enhanced rapidly by cement content within the high weight fraction range. From the results, it was observed that, the modulus were better enhanced in cement bonded white paper pulp with 60, 70 and 75 wt % white paper pulp which has values of 717.75, 301.57 and 242.94 N/mm^2, respectively.

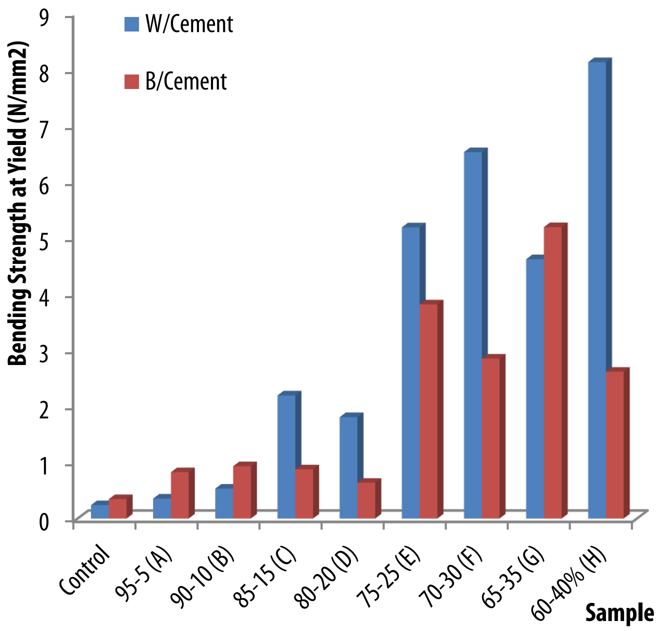

***Figure 5**: Plots of variation of Bending Strength at Yield with Samples*

The results of the bending strength at yield depicted in Figure 5 revealed similar pattern to that of bending strength at peak. Best results were obtained from 60, 70 wt % white paper pulp of cement bonded white paper pulp with values 8.13 and 6.53 N/mm^2 followed by 65 wt % brown paper pulp from cement bonded brown paper pulp with a value of 5.20 N/mm^2 . These values show brittle failure behavior because the yield strength coincided with the strength at peak values.

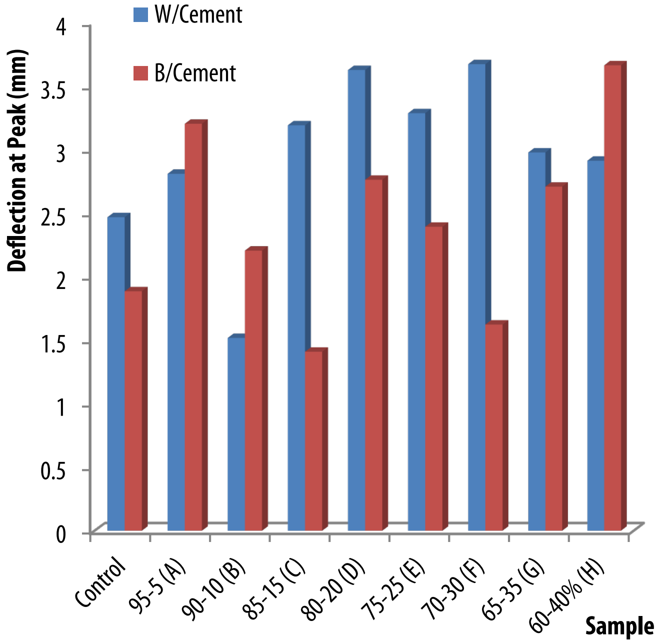

***Figure 6**: Plots of variation of deflection at Peak with Samples*

The responses of the deflection at peak show that all the samples possess comparatively good deflection response before failure. Both samples from low and high strength and stiffness possess good deflection response with values of about 3 mm compared to the control with values of 2.47 and 1.89 mm for white and brown paper pulp respectively. Cement bonded white paper pulp with 70 wt % white paper pulp has a value of 3.67 mm followed by cement bonded brown paper pulp with 60 wt % brown paper pulp having a value of 3.66 mm and cement bonded white paper pulp with 80 wt % white paper pulp of value 3.63 mm was next. All except cement bonded white paper pulp with 70 wt % white paper pulp exhibit weak strength and stiffness which is responsible for their high deflection at peak value. It follows from the results that composite material with good strength and stiffness as well as good deflection can be developed by using 70 wt % white paper pulp which is the average of the range of the weak and strong strength and stiffness for cement bonded white paper pulp composites.

Response of the materials to compressive properties.

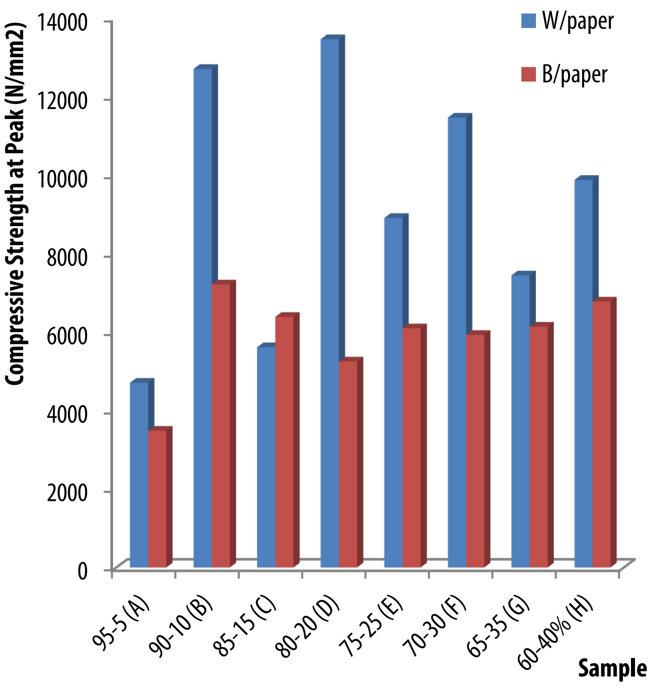

***Figure 7**: Plots of variation of Compressive Strength at Peak with Samples*

Figure 7 illustrates the behavior of the materials when subjected to compressive strength test. It was observed from the results that all except at 85 wt % white paper pulp cement bonded white paper pulp gave better enhancement in the compressive strength at peak than cement bonded brown paper pulp composites due to the reasons given in Figure 3. The best materials were composites with 80, 90 and 70 wt % white paper pulps with values 13454, 12700 and 11464 N/mm^2, respectively. The observed performance was the outcome of expected proper mixing proportion of cement and the white paper pulp. These show that there is mixing proportion for the materials that can give the best compressive strength at peak enhancement. It was noticed that the addition 70 wt % white paper pulp and 30 wt % cement has been the most suitable mixing proportions for the best combination of all the properties considered. Though not the outstanding best in most of the properties but has always appear as one of the best in most of the properties measured.

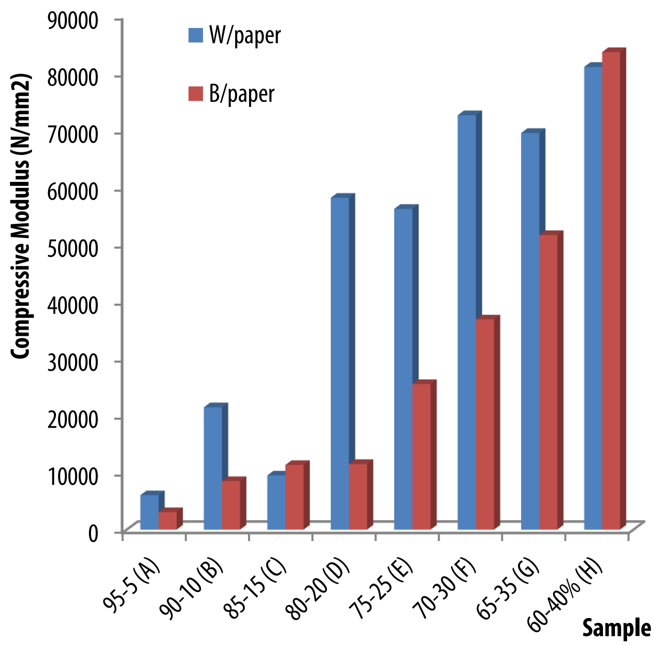

***Figure 8**: Plots of variation of Compressive Modulus with Samples*

The results of the compressive modulus were as shown in Figure 8. It was observed that the stiffness tends to increase as the paper pulp content increases. The trend seems to be contrary to the observed response in Figure 7. From the results, it was found that cement bonded brown paper pulp with 60 wt % brown paper pulp has the highest value of 83637 N/mm^2 followed by cement bonded white paper pulp with 60 and 70 wt % white paper pulp of values 81048 and 72619 N/mm^2, respectively.

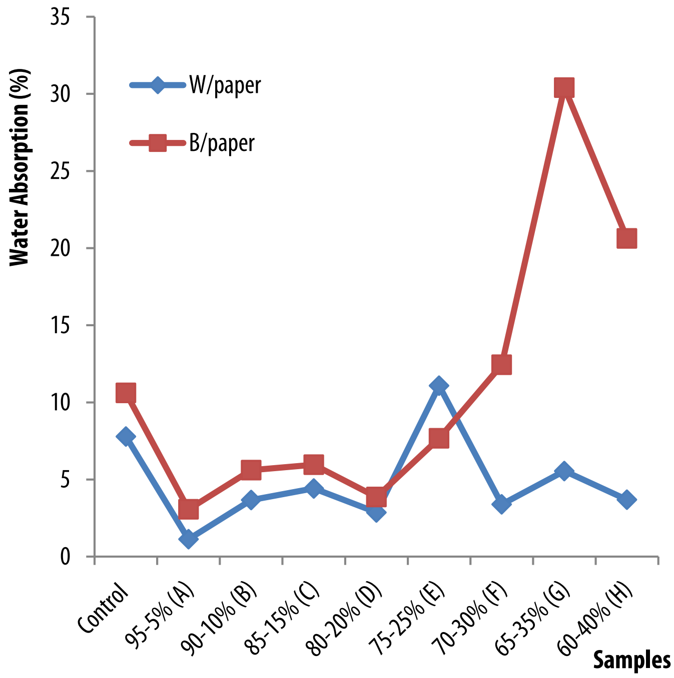

***Figure 9**: Plots of variation of Water Absorption with Samples*

Figure 9 shows the plots of the variation of water absorption properties with time for each of the samples for 7 hours. The results revealed that both white and brown paper board samples followed a similar trend. It was noticed that as the paper content increases, the rate of water absorption increases as a result of increase in the rate of diffusion of water molecule into the samples. This implies that, the addition of paper pulp tends to increase the pores present in the material. However, brown paper pulp reinforced samples absorbed much water than the white paper pulp samples. This may be due to the presence of lignin which tends to absorb much water in the brown paper. From the results, cement bonded white and brown paper pulps with 95 wt % white and brown paper pulps gave the best results with values 1.13 and 3.07 %, respectively. This was followed by cement bonded white paper pulp with 70 wt % white paper pulp content having a value of 3.39 %. This result further substantiates the superiority of 30-70 wt % cement bonded white paper pulp composites. The superb water resistance capability of the sample in addition to the excellent bending and compressive properties of the material has placed it above others.

CONCLUSION

This work has aided the necessity for paper sorting in the bid to use waste papers in a recycled form. These waste papers are readily available in offices and schools in Nigeria. They are usually burnt in most cases because they have not being put into economic use, thereby adding value to them. This work was carried out to shed more light into the use of these resources that are regarded as waste. The results showed that the properties of these two different sources of papers differ from one another and therefore, needed to be considered. From the results, the following deductions are made;

1. *White paper pulp gave better mechanical and physical performance than brown paper pulp when bonded with cement.*
2. *The best mixing ratio for excellent bending strength and stiffness was 60-40 wt % of white paper pulp to cement while 80-20 and 90-10 wt % white paper pulp to cement gave excellent compressive strength, on the other hand, 60-40 wt % brown and white paper pulps to cement gave the best compressive modulus.*
3. *The best mixing proportion was 70-30 wt % of white paper pulp to cement. At this mixing ratio, the best combination of both mechanical and physical properties were achieved.*
4. *The work confirms the prospect of the use of paper pulp filled cementitious composites developed from waste papers as potential structural engineering materials.*

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