From Take-away to Ride-away: An Innovative Reuse of Expanded Polystyrene (EPS) Container

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***Abstract*—Expanded polystyrene (EPS) or Styrofoam container, is a very popular take-away food packaging means for street food vendors in Malaysia. The widespread use of polystyrene however present a number of problems for both human health and the environment as reported in a number of studies. Processing disposed EPS containers are difficult and costly, plus very limited use of recycled EPS material prompted recycling or reuse of EPS to be largely ignored leading to persistent accumulation of disposed EPS. Initiatives were taken by researchers from University College of Technology Sarawak (UCTS) to develop new composite materials from reused EPS containers as lightweight core material for a bicycle frame, and a case study was conducted. Un-used and used EPS containers are collected and bonded to form panels. The layered composite EPS material were analysed to identify its physical and mechanical properties. Mathematical modelling and industrial design methods were applied in designing the bicycle frame prototype. The completed bicycle prototype was subjected to mechanical load test at an engineering testing facility in UCTS to determine the suitability of the sandwich composite structure material for its intended applications where tensile strength, stress rupture, and fatigue limit were measured. Comprehensive analysis of the material bonding and compression were essential to determine the load that the frame can withstand. The case study also showed the potential of financial income gained by the communities involved in the EPS container reuse or recycle activity. This activity can be upgraded into a programme to generate a profitable small or medium entrepreneurship (SME) venture for the local communities by collecting and supplying used EPS containers for the bicycle frame production.**

***Index Terms*—EPS, Environment, Reuse, Design**

I. Introduction

Expanded polystyrene (EPS) or Styrofoam (a registered trademark of the Dow Chemical Company) container, as commonly known, is a very popular take-away food packaging means especially for street food venders in Malaysia. It is considered as a convenient, versatile and cost-effective packaging by both vender and buyer, thus the use of polystyrene take-away containers is extensive. However, in 2011, the Malaysian State of Penang local authorities have begun campaigns on reducing the use of the inorganic container due to health and environmental concerns [1]. The widespread use of polystyrene present a number of problems for both human health and the environment as reported in a number of studies that suggest chemicals from polystyrene food packaging can leak into foods and drinks. In addition, manufacturing and subsequent disposal of used containers contributed to greenhouse gas emissions, landfill waste, the leaching of chemicals into the environment, and the loss of biodiversity [2,3]. Although no formal legislation has been introduced by the central government, the local authorities and city councils have implemented their own versions of legislation in order to reduce waste and supress concerns over food poisoning. Now, more cities and local authorities in Malaysia have banned polystyrene food packaging, with the list growing steadily [4, 5]. The move by these local authorities is seen as a significant step towards minimising the usage of polystyrene containers, and encourage the use of container that is eco-friendly and sustainable. Nevertheless, the efforts to clean the environment of the already disposed polystyrene containers are difficult and costly.

II. Research Initiative

There is currently no systematic nor effective method of disposal, recycle or reuse in Malaysia. The researches [6, 7, and 8] conducted to establish the most appropriate methods by scientists and academicians have not seen any actual application. In fact, there is very limited domestic use of recycled polystyrene material which leads to persistent accumulation of disposed polystyrene not just in landfills but elsewhere (Refer to Fig. 1). Recycling or reuse of polystyrene has been largely ignored by the authorities concerned. Consequently, initiatives were taken by researchers from University College of Technology Sarawak (UCTS) who were analysing alternative materials to develop new composite materials intended to be used to build a recreational product, to reuse the polystyrene container as lightweight core material for a bicycle frame. The use of injected Polystyrene foam structural core is a common choice for construction of lightweight composite products such as wind turbine blades [9], surf boards, as well as door panels (Refer to Fig. 2). However, there was previously no significant attempt to construct bicycle frames with used polystyrene containers. The abundance of used polystyrene containers currently provides unlimited

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supply of free and lightweight material suitable for the purpose. As used polystyrene containers vary in sizes and need to be cleaned before they can be used, an appropriate processing method was formulated.

Figure 1. Unscrupulous disposal of polystyrene containers posed danger to the environment

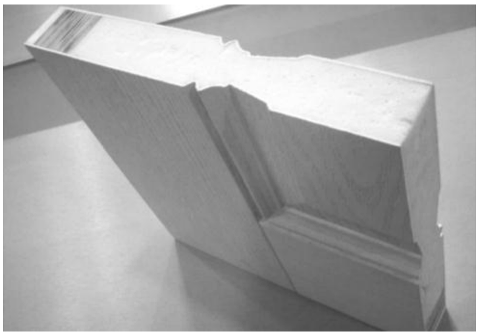

Figure 2. Cross section of modern lightweight door that uses injected virgin EPS material as inner core of the door panel

III. Case Study

The initiative was conducted as a case study into experimenting suitable cost effective materials as structural core for a composite recreational bicycle frame. Expanded polystyrene (EPS) is the key material used in the experiment. Compared to injected virgin cross-linked PVC material that is commonly used as structural core, the material properties of used polystyrene are still basically unknown. This case study also looks into analysing the structural properties of the reused polystyrene container. The following paragraphs described the methods and processes (Refer to Fig. 3) fundamentals, and outputs of the case study.

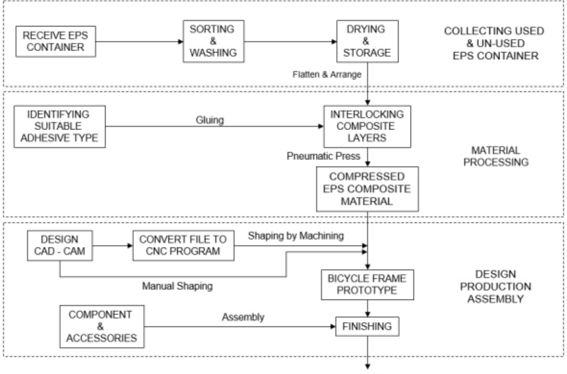

Figure 3. A simplified flowchart of the method and process used

A. *Method and Process*

In order to have a sufficient amount of polystyrene containers that may be applied in the experiment, un-used and used polystyrene containers are collected from disposal sites around the research facility. The collected materials are then sorted for any damages and tears before being washed thoroughly to get rid of oil or grease from the surface of the materials. The cleaned materials are then dried and stored for the next process.

Concurrent to these tasks, experiments were also conducted to identify the most suitable adhesive type to create composite bonding. Several adhesive types were tested including Poly-vinyl acetate (PVA) based, Polyurethane (PU) based, and Epoxy (Solvent free) based. These adhesives were tested on their drying time, flexibility, and strength of bonding. However perhaps the most important consideration of all is they do not dissolve the surface of the polystyrene. Each adhesive was applied to several layers of polystyrene to create a 1 inch thick sandwich composite sample by compressing the layers at specific pressure and time. The completed samples were then placed on a peel test. Following the result, PU based adhesive was selected.

Figure 4. Technician arranging the flattened polystyrene container before beginning compressing process

To create the structural core material for the bicycle frame, the cleaned polystyrene containers are flattened, glued and arranged symmetrically in wooden templates to form interlocking composite layers (Refer to Fig. 4). The wooden templates holding the polystyrene layers were then transferred onto a pneumatic press machine. A specific pressure was applied to compress the layers. The completed composite polystyrene material was analysed to identify its physical/mechanical properties and the results are as shown in the following table (Refer to Table I).

TABLE I. Physical and Mechanical Properties of Compressed Used Polystyrene Composite Samples

Property	Test	Units	2kg	2.5kg	3kg
Density	ASTM D1622	Kg/m³	62	87	103
Tensile Strength	ASTM D1623	N/mm²	1.4	2.3	3.0
Tensile Modulus	ASTM D1623	N/mm²	91	128	152
Compressive Strength	ASTM D1621	N/mm²	0.62	1.15	1.50
Compressive Modulus	ASTM D1621	N/mm²	38	63	80

B. Design and Prototyping

Industrial design [10, 11] process was applied from conceptualisation of ideas until the final design of the bicycle frame. The majority of the industrial design processes were done digitally by utilising advanced 3D CAD and CAM software (Refer to Fig. 5).

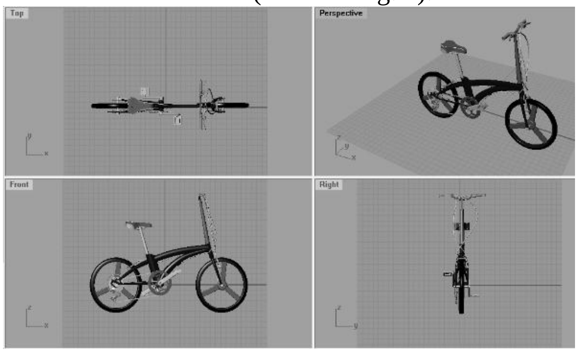

Figure 5. A screenshot of three-dimensional design of the bicycle frame done using commercially available CAD/CAM software

For the case study, a small recreational bicycle frame design was proposed as this will allow the researcher to experiment with minimum amount of material on the physical and mechanical performances, and the forms of design. The frame size (18.5” – 19.0”; top tube length in inches) was chosen according to a standard BMX size [12] for rider with 5’ overall height. The final design of the prototype bicycle frame (structural core) was cut out from the material manually, although for commercial production, CNC machining is suggested (Refer to Fig. 6).

Figure 6. The prototype bike frame (structural core) was cut out from the material manually although CNC machining is recommended for commercial production

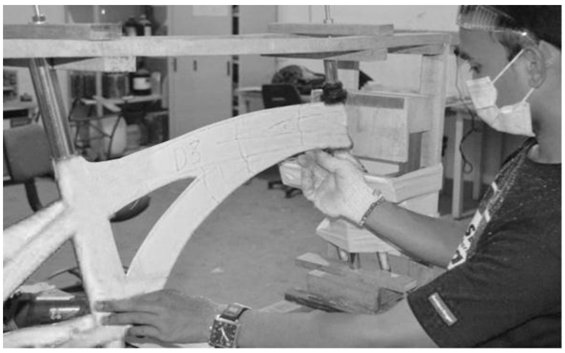

Figure 7. A dedicated custom assembly jig is fabricated to facilitate assembly of the bike frame

Contouring and shaping the frame prototype in order to strengthen the surface was also done manually. For the assembly process, the frame was set on a purposed built jig to facilitate precise alignment with other sections. The rear triangle (seat and chain stay section) is then attached to the structural core followed by insertion of the head tube and the bottom bracket axle sections (Refer to Fig. 7). Once the structural core and all other sections were attached the finishing process can start.

In determining the stress for this bicycle, a method called Finite Element Analysis (FEM) was employed. The analysis is to check the ability of the bicycle in withstanding the weight due to the user. This allow a check into the structure to check the stress concentration typically occurring in a bicycle structure.

The analysis involves determining the stress. As stress is defined as [1]

$$\Delta\delta = \frac{F}{\Delta A} \qquad [1]$$

Where $\Delta\delta = Stress$
$F = Force$
$\Delta A = Area$

By applying a typical load, 60kg and up to 80kg, it is found the bicycle are able to withstand the stress being introduced, the stress was well below tolerable load.

C. Finishing and Assembly

As outer-most layer (or representative skin) of composite frame uses woven carbon fibre material, the author had decided to apply a similar material on the frame prototype. Before the carbon fibre material is applied onto the frame, a thin layer of solvent free epoxy based adhesive membrane tape was wrapped around the frame. This membrane hardened after being exposed to the air for more than half an hour. This technique protects the soft polystyrene structural core from any damages during layering process with carbon fibre, apart from strengthening the attachment of the rear triangle and other sections to the main frame.

Figure 8. An example of heated steel mould used in production of carbon fibre bike frame (Source: www.ibisbicycle.com)

While waiting for the frame to completely hardened, the woven carbon fibre was prepared and cut according to the size of the frame. The process of applying the carbon fibre did not require any heated mould (Refer to Fig. 8) as with common resin injected carbon fibre products. For this prototype, several layers of cut woven carbon fibre material were applied manually around the frame with PU based adhesive and hardened in an oven with set maximum temperature of 80 ℃ for about 40 minutes. The hardened bike frame prototype was taken out and allowed to cool down before proceeding with the aesthetic finishing. The rough surface of the frame was smoothened manually by using sand papers to remove any visible surface irregularities before the frame can be painted. The final painted frame was turned into a complete recreational bicycle with assembly of the wheels and other accessories (Refer to Fig. 9).

Figure 9. The completely assembled recreational bike constructed from reused expanded polystyrene (EPS) take-away food container

IV. RESULTS AND DISCUSSION

A mechanical load test was conducted on the completed bike frame at an engineering testing facility in UCTS. The test was required to show whether the sandwich composite structure material was suitable for its intended applications by measuring the tensile strength, stress rupture, and fatigue limit. The result of the test showed that the completed frame was able to hold out a maximum load of approximately 100 kg. The ability to hold 100kg of load was an outstanding result, considering the maximum weight of riders suitable for this category of bicycle is 70kg [13], the material was suitable for the bicycle frame construction. Apart from testing with a mechanical test device, the completed bicycle was subject to actual ride tests on a variety of track surfaces for a specific distance. However, no test was conducted on the effect of impact on the frame. Impact test is generally conducted to investigate the effect of impact induced damages that are expected to occur during the lifetime of the tested product. The researcher considered it was not necessary to conduct the test at the moment as priority was given to comprehensive analysis of the material bonding and compression, the two aspects that were essential to determine the load that the frame can hold.

Another benefit that was discovered during the case study was the potential of financial income gained by the communities involved in the polystyrene container reuse and recycle programme. This project can be upgraded into a programme to generate a profitable small or medium entrepreneurship (SME) venture for the local communities by collecting and supplying used polystyrene containers for the bicycle production. The more proficient entrepreneurs may involve in localised production of the bicycle frame within their own community which enable individual suppliers to quickly sell their used polystyrene containers without having to search for buyers elsewhere. The potential for entrepreneurship ventures would encourage the collection of used polystyrene containers thus reducing unscrupulous disposal of the containers. And perhaps this initiative could also help in cleaning the environment of disposed polystyrene containers. The initiatives however still require further studies especially in the perspective of socio-economics.

V. CONCLUSION

The enforcement of legislations banning the use of polystyrene food containers by several local authorities in Malaysia has triggered conscience among the public about the effects of the material towards human health and the environment. However, the use of the material is still prevalent in most part of the country and there is still no significant effort to recycle or reuse the disposed polystyrene containers. The initiative to develop a reused programme by researchers from UCTS is still in the infancy stage and further research and development are required to ensure the feasibility of the programme. An in-depth analysis of the composite used polystyrene materials needs to be conducted to establish the final material properties. The output of the analysis is vital to identify the suitable product for the material.

Nevertheless, the potential benefits gained from implementing the reuse programme are huge especially for the local communities as the programme could generate additional sources of income. Their participation in collecting used polystyrene containers could also help to reduce the local authorities' expenditure for waste treatment and management. Thus, the reuse of polystyrene food containers for other applications is not just cost effective; it also plays a very significant role in minimising polystyrene effects toward the environment

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