REUSE OF COMPRESSED EXPANDED POLYSTYRENE (EPS) CONTAINERS FOR BIKE FRAME CONSTRUCTION IN SME’S

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ABSTRACT

The extensive use of Expanded Polystyrene (EPS) containers in the take-away food businesses throughout the world has led to excessive dumping of used EPS containers in landfills, and aggravated by unscrupulous disposing of this material had caused severe threats to the natural environment and wildlife. Recycled EPS material currently has little uses to compensate the high cost of recycling process therefore the idea of recycling EPS is generally ignored. Reused approach is considered more cost effective and energy efficient. This paper describes a case study that was conducted to address the issue. A research was carried out to analyse the reused of EPS as alternative material for bike frame construction. This research involved material testing, design, development and construction of bikes main frame with compressed used EPS containers. Material preparation was done by arranging several layers of EPS containers symmetrically to form interlocking layers. Bike frames were then cut from the compressed material. Mechanical load tests were done on completed frames prototype to assess structural strength, and fully assembled bike prototype was put to scheduled rides to assess its durability. The reused of EPS container created optimism in minimising environmental threats of polystyrene besides providing benefits to local SME’s.

Keywords: Environment, EPS, reuse, bike frame

1. INTRODUCTION

Expanded polystyrene (EPS) or Styrofoam (a registered trademark of the Dow Chemical Company) container is a very popular take-away food packaging means especially for street food venders in Malaysia. Locally known as “Tapau” by the communities of Sarawak region in Malaysian Borneo, it is considered as a convenient, versatile and cost-effective packaging by both vender and buyer. Thus, the use of polystyrene take-away containers was extensive. However, in 2011, the Penang state government and 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 presents a number of problems for both human 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 version of legislation in order to reduce waste and supress concerns over food poisoning. Now, more cities and local authorities in Malaysia [4,5] have banned polystyrene food packaging, with the list growing steadily. The move by these local authorities is seen as a significant step towards minimising the usage of polystyrene container, and encouraged usage of container that is eco-friendly and sustainable. Nevertheless, the efforts to clean the environment of the already disposed polystyrene containers are rigorous and costly.
2. RESEARCH INITIATIVE

There is currently no systematic method of disposal, recycled or reused in Malaysia [6] compared to the USA and EU countries. In fact, there is very limited use of recycled polystyrene material which leads to persistent accumulation of disposed polystyrene not just in landfills but elsewhere (Refer to Figure 1). Recycling or reuse of polystyrene has been largely ignored by the authorities concern. Consequently, initiatives were taken by researchers from Universiti Malaysia Sarawak (UNIMAS) who were analysing alternative materials to develop new composite material intended to be used to build recreational product, to reused the polystyrene container as lightweight core material for bike frame. The used of injected Polystyrene foam structural core [7] is a common choice for construction of lightweight composite products such as wind turbine blade, surf board, as well as door panel (Refer to Figure 2).

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

However, there was previously no significant attempt to construct bike frame with used polystyrene container. The abundance of used polystyrene containers currently provides unlimited supply of free and lightweight material suitable for the purpose. As used polystyrene containers varies in sizes and need to be cleaned before it can be use, an appropriate processing method was formulated.

3. CASE STUDY

The initiative was conducted as a case study into experimenting suitable cost effective materials as structural core for composite recreational bike frame. The case study was conducted through both laboratory experimentations and field trials. The laboratory experimentations were mostly to explore the basic stress analysis to determine the new material properties. Whereby, the field trials were conducted to investigate and analyse qualitatively the usage practicability of the new material in actual applications. The duration of the case study took about 12 months. Expanded polystyrene (EPS) was 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 the composite EPS are still basically unknown although some testing were done previously on recycled polystyrene [8]. In general, composite material
consist of the matrix and filler, thus in this case study, epoxy type polymers is used as the matrix and EPS as the filler. Laminate type composite was chosen and several samples were created. This composite samples are non-homogeneous, thus the resulting properties are normally the combination of the properties of the constituent materials. This article however, will not discuss the actual material equation used in the frame design application. The following paragraphs described the fundamentals of the material preparations and outputs of the case study.

3.1 Method and Process

In order to have sufficient amount of polystyrene containers to 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 out 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 adhesive were tested on their drying time, flexibility, and strength of bonding. But 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 peel test. Following the result, PU based adhesive was selected.

To create the structural core material for the bike frame, the cleaned polystyrene containers are flattened, glued and arranged symmetrically in wooden template to form interlocking polystyrene laminate layers (Refer to Figure 3). The wooden template holding the polystyrene layers was then transferred onto a pneumatic press machine. A specific pressure was applied to compress the layers. The completed composite polystyrene material were tested to identify its physical/mechanical properties (Refer to Table 1).

3.2 Design and Prototyping

Nowadays, industrial design plays an integral part of design and development [9]. Industrial design process was applied from conceptualisation of ideas until the final design of the bike frame. Majority of the industrial design processes were done digitally by utilising advanced 3D CAD and CAM software (Refer to Figure 4).

<table>
<thead>
<tr>
<th>Property</th>
<th>Test</th>
<th>Units</th>
<th>2kg</th>
<th>2.5kg</th>
<th>3kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>ASTM D1622</td>
<td>kg/m³</td>
<td>62</td>
<td>87</td>
<td>103</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>ASTM D1623</td>
<td>N/mm²</td>
<td>1.4</td>
<td>2.3</td>
<td>3.0</td>
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<td>Tensile Modulus</td>
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<td>N/mm²</td>
<td>91</td>
<td>128</td>
<td>152</td>
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<tr>
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<td>N/mm²</td>
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<td>1.15</td>
<td>1.50</td>
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<tr>
<td>Compressive Modulus</td>
<td>ASTM D1621</td>
<td>N/mm²</td>
<td>38</td>
<td>63</td>
<td>80</td>
</tr>
</tbody>
</table>

Table 1: Results of physical and mechanical properties of the compressed used EPS composite.

Figure 3: Technician arranging the flattened polystyrene container before compressing process.

Figure 4: Final design of the bike frame is done with the latest 3D software.
For the case study, a small recreational bike frame design was proposed as this allowed the author to experiment with minimum amount of material on the physical, mechanical performances, and forms of design. The final design of the prototype bike frame (structural core) was cut out from the material manually, although for commercial production, CNC machining is suggested (Refer to Figure 5).

Contouring and shaping the frame prototype in order to strengthen the surface was also done manually (hand-made). For assembly process, the frame was set on a purpose built jig to facilitate precise alignment with other sections. The rear triangle (seat and chain stay section) was then attached to the structural core followed by insertion of the head tube and the bottom bracket axle sections (Refer to Figure 6). Once the structural core and all other sections were attached the finishing process can start.

3.3 Finishing and Assembly

As most outer layer (or representative skin) of composite bike frame uses woven carbon fibre material, the author had decided to apply 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. 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 Figure 7) 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 oven with set maximum temperature of 80°C for about 40 minutes.
The hardened bike frame prototype was taken out and allowed to cool down before proceeding with the aesthetics 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 bike with assembly of the wheels and other accessories (Refer to Figure 8).

4. RESULTS AND DISCUSSION

The major advantages of using used EPS container material as filler for the new composite material are in environmental protections and weight savings. Used EPS containers will be systematically re-used to manufacture new products – bike frame. This approach was anticipated to help reducing the current practice of unscrupulous disposal of used containers thus minimising polystyrene in landfills and the environment. In terms of weight saving, this advantage was illustrated in the strength to weight ratio. For the bike frame design, the new composite material was strong enough to withstand the load that was applied as shown the calculation below (eq):

\[
\frac{1.0 \text{kN} \times 1000 \text{g}}{8.91 \text{N}} = 112.23 \text{ kg}
\]

A mechanical load test was conducted on the completed bike frame at an engineering testing facility in UNIMAS. 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 more than 100 kg. The ability to hold more than 100 kg of load was an outstanding result, considering the average weight of adult riders suitable for this category of bike is 70 kg [10, 11], the material was suitable for bike frame construction. Apart from testing with mechanical test device, the completed bike was subject to actual ride test on variety of track surfaces for 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 author considered it was unnecessary 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 significant benefit that was discovered during the case study was the potential of financial incomes gained by the communities involved in...
the polystyrene container reuse and recycle programme. This project can be upgrade 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 bike production. The more proficient entrepreneurs may involve in localised production of the bike 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 collecting of used polystyrene containers thus reducing unscrupulous disposal of the containers. And perhaps this initiative could also help in clearing the environment of disposed polystyrene containers. The initiatives however still require further studies especially in the perspective of socio-economics.

5. CONCLUSION

The enforcement of legislations banning the use of polystyrene food container 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 used polystyrene containers. The initiative to develop a reused programme by researchers from UNIMAS is still in the infancy stage and further research and development are required to ensure the feasibility of the programme. In-depth analysis of the composite used polystyrene materials needs to be conducted to establish the actual material properties. The output of the analysis is vital to identify the suitability of products 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 source of income. Their participation in collecting used polystyrene containers could also help to reduce the local authorities’ expenditure for waste treatment and management. Thus, reused of used expanded polystyrene food container for other applications is not only cost effective, it also plays a very significant role in minimising polystyrene effects toward the environmental

6. ACKNOWLEDGEMENTS

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