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A Review on Recycled Expanded Polystyrene Waste as Potential Thermal Reduction in Building Materials

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Abstract. Expanded Polystyrene (EPS) is a common application mainly for construction materials and packaging for consumer products. EPS also has been chosen as recycled material due to the contribution towards non-biodegradable material when it exposed to the landfill. In addition, this waste will also create harmful to our environment due to its toxicity and recalcitrant compounds. The recycled waste material will benefit when it actually can reduced the heat from building material at low cost application. This eco-friendly product will reduce the process of heat transfer between objects. Hence, it plays a great role as an insulator and also benefit in consuming the energy efficiency. A review has been made regarding the availability and performance of polystyrene waste to the market. By recycling this material, a minimization of waste generation can be implemented from the source. Even though the EPS has the ability to reduce heat but sometimes it will create consequences on its products especially low in strength and low in fire resistance. Therefore improvement has been made to sustain the application of recycled EPS in market. As conclusion, recycling EPS will generates wealth from waste, utilize a simple technology that can sustain energy, cheap and safe to public.

Keywords: Expanded polystyrene; Recycled material; Recalcitrant compounds; Eco-friendly product; Minimization

1. Introduction

Polymeric materials are a unique product whereby it exhibit different durability based on its backbone of a chain. World nowadays produce this product massively in order to fulfill the needs and requirement of packing industry. As this product continuously increase, the total amount of plastics that ends up in waste stream is in a similar trend. This has lead towards the increment cost of landfill disposal (Hamad et al., 2010). Therefore it is important to optimize the waste by applying various practical approaches such as prevention, minimization, reuse or recovery (Vilapana and Karlsson, 2008).

Previous research has proved that this EPS product can improve the heat impact by having a very low thermal conductivity value (Papadopoulos, 2005). This is due to its characteristic which is closed in cell. Jebsen & Jessen Company which is also the manufacturer for insulation foam has produced a virgin EPS which has a fire retardant protection as well as good in termite resistance treatment.

Normally the phenomenon of heat generated during the day, will be stored at the building and it being released to environment at night. Hence, by producing the recycled EPS into an insulation product it is hope

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that it can prevent the heat from entering into a building. This review aimed is to achieve the availability information mainly on recycling the EPS and the drawbacks of recycling to the industry.

In Malaysia, there are few numbers of industries that typically recycle the polymeric material into new EPS product. Basically there are two type of plastic resins mainly thermoplastics and thermosets. Polystyrene is a thermoplastic family and very suitable materials for recycling (Acierno et al., 2010). This is because thermosets cannot be re-melted but thermoplastic can be recycled and change into different types of recycled polystyrene by altering its properties (Othman et al., 2008).

Therefore, there are several factors that need to be considered mainly the availability of waste product, how much the amount of waste is being generated. Recycling has been the concern including eco-efficiency, corporate social responsible and how quality and traceability of product is been taken into account (Maharana et al., 2007).

2. Importance of Expanded Polystyrene

EPS has become an alternative to traditional plastic commodity and it is an eco friendly polymer. There are two types of polystyrene mainly solid PS and the EPS. The solid PS such as coffee cups can recycle and synthesis its properties to original resin, which can be used for other application such as videocassette cases and office equipment (Maharana et al., 2007). National Polystyrene Recycling Company had revealed that the PS foam egg cartons can be recycling into so many times.

EPS also good in packaging product having shock absorbing properties, low cost and ease of processing (International Trade Center UNCTAD/WTO). EPS also being used as insulating materials in construction building material due to its characteristic which having long term compressive stress (Gnip et al., 2008). This phenomenon can develop more reliable models for predicting creep strain development by extrapolation and consistency. As been stated by Doroudiani and Omidian, 2010, EPS is an attractive material because of low in material usage, less costly during installation, good performance and resist to moisture. Another characteristic of EPS it has low value of thermal conductivity. Unmodified EPS foams have a cellular microstructure with closed cell membranes made of EPS and its density is typically less than 50kg/m^3 (Kan and Demirboga, 2009).

EPS can be recycled until infinity times. Generally there are different grade of polystyrene. The most common recycling polystyrene had been made with when a single grade of plastics in form of scrap is being process from which it originated. This process is an independent recycler and the processing is cheaper replacement compare to the virgin material (Drain et al., 1981).

3. Availability of EPS accepted for recycling and its method.

Basically, the EPS from packaging is white in material and it has two types mainly clean post consumer or dirty post consumer. This box is normally used in order to sustain the temperature level in its box. The other accepted polystyrene materials are serving school trays, polystyrene cups, plates and bowls, packaging used to protect electronic and computers, egg cartons, and small packaging of peanuts.

Study revealed by Naguchi et al., 1998, there are three methods used to recycling the EPS. Mechanical recycling usually requires the combination of high temperatures & shear stresses (energy consumption). Chemical recycling usually requires depolymerisation of the recycle material through solvolysis and thermal catalytic (Melo et al., 2009).

In this review, we only focus on the mechanical recycling. It is preferable due to the optimization of energy and minimizing gases emission that can contribute towards global warming (Finnveden et al., 2005). It is also simple and low in cost technique. Vilaplana and Karlsson, 2008 added that mechanical recycling is relatively clean and homogeneous plastic waste stream. Acierno et al., 2010 added that after the separation is being made, EPS can use different ways:

i. Mechanically recycled and used as filler for moulding of new EPS Products.
ii. Ground in chunks and used as aggregate for the production of light mortars and concrete.
iii. Transform into compact polystyrene (PS) then extruded.
iv. Chemically recycled to produce styrene and other organic products.

Basically the sample is being characterized accordingly based on several methods that conformed based on European standards from European Committee for Standardization (CEN). Normally the polystyrene chunks will be blend with other mixed plastic waste mainly PP, PET, LHDP and PS. The blended polymer normally is imcompatible and poor adhesion properties in polymeric mixture interface (Vilapana and Karlsson, 2008). Compatibilizer are additives to improved the physical properties of blends of incompatible polymers by promoting adhesion at the domain interfaces, thereby permitting the transmission of stresses from one phase to another. The important of filler in polymer can enhance compatibility of polymer blends (Datta and David, 1996). Hence, in order to achieved the sustainable society obtained by this material we need to challenge by combining the scientific knowledge towards efficiency in recycling product.

4. Drawback and improvement towards Recycling the Expanded Polystyrene

Table 1 Drawback and improvement towards Recycling the Expanded Polystyrene

No	Drawback of recycling EPS	Literature Review	Description	Improvement
1	Failure of strength and appearance at the surface of wall	Teo *et al.,* (1997) stated more than 50% of the roughness of the surface and the strength decreases with the increment of mixing recycled product and virgin.	During the mixing of the virgin with recycled in pre expansion and molding stage, the pentane gas is being impregnated into EPS beads and causes the virgin to expand. Unlike for the recycled EPS which has already break it cells during grinding process. At this stage very less pentane gas left hence the recycle has no longer expand.	To improve the impact strength, polybutadiene is generally added to polystyrene, in the amount of 5 to 10 % (La Coste et al., 1998). Another method which is hope can increase the strength of EPS is by adding some additive and natural fiber as to strengthen the bonding between each particle. These has been proved by Ochi, 2008 the more content of fiber reinforced the better the strength of a composite material.
2	Low in density	The impact of transportation (Acierno et al., 2010)	A nearer place needed to recycle the EPS waste	Hence if we can have the recycling center nearer with the production industry will be the most economical.
3	Legislation for fire safety	Legislation needed to minimize the hazard due to the use of flammable materials in construction (Diamant, 1986).	The insulating material having very low value on thermal inertia whereby the flammable is inversely proportional to the thermal conductivity, density and heat capacity (Stec and Hull, 2010). When the EPS is subjected to high temperature, the cell walls started to soften and collapse the cellular structure which the foam started to contract. According to ((Bynum, 2001),(Papadopoulos, 2005) and (Al-Homoud, 2005)) as cited in Vaou and Panias, 2010 when the EPS is subjected to direct sunlight or temperature higher than 80°C the EPS started to breaks down gradually and reacts with common solvent.	One of the patent that has been discovered by Peterson, 2008 is by coating the PS beads with relatively low cost, non-commercial liquid in tumescent fire retardant. This fire resistant also comprises a binder component such as methyl cellulose or other glue or waste resistant material. Another study revealed that a safe house is said to be safe with the mixing of Expanded Polystyrene foam with cementations coating (Lee et al., 2006). They also claim that during the test the flame did not spread beyond the wood orib structural integrity in spite of heat stresses.
4	Flammability	The toxicant under flammable conditions most probably is from styrene monomer	It also gives of the carbon monoxide (CO), carbon dioxide (CO_2), water and soot (black smoke) (Doroudiani and Omidian, 2010).	Wang et al., as cited in Doroudiani & Omidian, 2010, the reduction in the heat release rate of PS stabilized with transition metals halides,

	(Gurman et al., 2004).	phosphate ester, which acts as cross linking. This additive diminishes the mechanical properties. This research continued by having effect of clay improves the flammability resistance together with the mechanical properties.

5. Types of thermal insulation and its application

There are two main categories of thermal insulating materials which known as organic and inorganic compound. The most widely used for organic products are EPS and XPS. As for the inorganic material which has been stated by Vaou and Panias, 2010 there are fibrous glass wool and stone wool. This inorganic material normally is not good in terms of fire resistance.

Table 2 Generic table describing types and ranges within types. (Papadopoulos, 2005)

Insulation	**Density range (kg m^{-3})**	**Thermal conductivity range (W m^{-1} K^{-1})**
Glass wool (GW)	10–100	0.030–0.045
Stone wool (SW)	22–180	0.033–0.045
Extruded polystyrene (XPS)	20–80	0.025–0.035
Expanded polystyrene (EPS)	10–50	0.029–0.041
Phenolic (PhF)	30–40	0.029–0.041
Polyurethane (PUR)	30–80	0.029–0.041
Polyisocyanurate (PIR)	30–80	0.023–0.041

Insulation material mainly can reduce the heat which is very hot and humid temperature from entering a building. Panyakaew and Fatios, has revealed that the used of agricultural waste materials such as bagasse, rice hulls, coconut husk, corn stalk, and durian peel can replace the insulating materials and can also reduce the energy consumed by air conditioning can be saved.

Vous and Panias, 2010 discovered that the insulating material from geopolymer (amorphous aluminosilicate volcanic glass) has the best and excellent properties in terms of thermo physical properties. Lindt et al., 2008 discovered that fly ash scrap tire fiber composite has increases the efficiency of insulator and also help to reduce the environment issues mainly on the disposal of waste product.

Generally there are so many waste product mainly polystyrene used for insulation as to prevent the heat transfer into the building. Gentel and Lacey,1999 had invented that waste packed recycled polystyrene cups can be sandwich between grade medium density fibre boards bonded with foamed polyurethane and has giving a result of very small value of thermal conductivity which is 0.15 $Wm^{-1}K^{-1}$ compared to Cengel, 1997 as cited in Gentel and Lacey the value of a brick is 0.71 $Wm^{-1}K^{-1}$.

6. Conclusion

To achieve the sustainability society, recycling the EPS waste that normally dumped to the landfill can be reduce but also producing a low cost building material mainly insulator. A different strategy and method has been invented by previous researchers in order to produce the maximum percentage of polystyrene waste as insulation material with a maximum strength, fire retardant properties and most important safe to the public.

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8. References

[1] Acierno, S., Carotenuto, C. and Pecce M. Compressive and Thermal Properties of Recycled EPS Foams – *Polymer-Plastic technology and Engineering.* 2010, 49: 13-19

[2] Al- Homoud, M.S. Performance characteristic and practical applications of common building thermal insulation materials, *Building and Environment*. 2005, 40;353-366

[3] Bynum, R.T. *Insulation Handbook*, McGraw-Hill, 2001

[4] Cengel, Y.A. *Introduction to thermodynamics and heat transfer,* New York: McGraw- Hill, 1997

[5] Datta, S and David, J.L. *Polymeric Compatibilizers* :Used and benifits in Polymer Blends. Munich, Vienna and New York : Hanser/Gardner Publications, Inc.,Cincinnati.1996.

[6] Doroudiani, S. and Omidian, H. Environment, health and safety concerns of decorative mouldings made of expanded polystyrene in bulidings – *Building and Environment*. 2010, 45: 647-654

[7] Diamant, R.M.E. *Thermal and Acoustic Insulation*. 1st ed. Butterworths Litho Preparation Department,Cambridge: Butterworths. 1986.

[8] Drain, K.F., Murphy, W.R. and Otterburn, M.S. Polymer Waste – Resource Recovery - *Conservation & Recycling.* 1981, 4(4): 201-218

[9] Finnveden, G., Johansson, J., Lind, P. And Moberg, A. *J.Cleaner Production*. 2005, 13:213.

[10] Frost and Sullivan Web Site "Solid Waste Recycling – The Malaysian Perspective, Available at: http://www.frost.com/prod/servlet/market-insight-top.pag?docid=92830160, Accessed 22 April 2011

[11] Gentel, C.R. and Lacey, M.R. Design of a novel insulated construction material, *Materials & Design.* 1999,20; 311-315

[12] Gnip, I.Y., Vaitkus, S., Keršulis, V. and Vėjelis, S. Long-term prediction of compressive creep development in expanded polystyrene, *Polymer Testing*. 2008, 27; 378-391

[13] Gurman, J.L., Baier, L., Levin, B.C. Polystyrenes: A review of the literature on the products of thermal decomposition and toxicity. *Fire and Materials*. 2004, 11: 109–130

[14] Hamad, K., Kaseem, M., and Deri, F. Effect of recycling on rheological and mechanical properties of poly (lactic acid)/ polystyrene polymer blend , Springerlink. 2010.

[15] Kan, A. and Demirboga, R. A new technique of processing for waste-expanded polystyrene foams as aggregates – *Journal of Materials Processing Technology*. 2009, 209: 2994-3000

[16] La Coste, J., Delor, F., Singh R.P., Vishwa Prasad, A., Sivaram S.,J. Polybutadiene content and microstructure in high impact polystyrene, *Applied Polymer Science*. 1998, 59; 953-959

[17] Lee, A.J, Kelly, H., Jogoda, R., Rosenfeld, A., Stubee, E., Colaco, J., Gadgil, A., Akhbari, H., Norford, L., Affordable, safe housing based on expanded polystyrene (EPS) foam & a cementitious coating. 2006. 41; 6908-6916

[18] Lindt, J.W, Carraro, J.A.H, Heyliger, P.R, and Choi, C. Application and feasibility of coal fly ash and scrap tire fiber as wood wall insulation supplements in residential buildings, *Resources, Conservation and Recycling.* 2008, 52; 1235-1240

[19] Maharana, T., Negi, Y.S., and Mohanty, B. Review Article: Recycling of Polystyrene, *Polymeric- Plastics Technology and Engineering.* 2007, 46;729-736

[20] Melo, C.K., Soares, M., Melo, P.A. and Pinto J.C. In Situ Incorporation of Recycled Polymer in Suspension Polymerizations – *10th International Symposium and Process Systems Engineering* – PSE Rita Maria de Brito Alves, Claudio Augusto Oller do Nascimento and Evaristo Chalbaud Biscaia Jr. (Editors), 2009.

[21] Morgan AB, Chu, L.L, Harris J.D. A Flammability Performance Comparison between Synthetic and Natural Clays in Polystyrene Nanocomposites. *Fire and Materials.* 2005, 29; 213

[22] Noguchi, T. and Kazuki.H.T. A new recycling system for expanded polystyrene using a natural solvent. *A new recycling technique.Packaging Technology.* 1998, 11: 39-44

[23] Ochi, S. Mechanical properties of kenaf fibersand kenaf/PLA composites, *Mechanics of Materials*. 2008, 40;446–452

[24] Othman, N., Basri, N. E. A., Yunus, M. N. M., and Sidek, L,M. Determination of Physical and Chemical Characteristics of Electronic Plastic Waste (Ep-Waste) Resin Using Proximate and Ultimate Analysis Method, International Conference on Construction and Building Technology. 2008.16; 169-180

[25] Panyakaew, S, Fotios, S, Agricultural waste materials as wall insulation for residences in Thailand: results from a preliminary study

[26] Papadopoulos, A.M. State of the art in thermal insulation materials and aims for future developments, *Energy and Buildings*. 2005, 37;77-86

[27] Peterson, T.E.*Thermal Insulation Product Formed From Waste Polystyrene.* Patent number US0246445A1, 2009

[28] Stec, A.A. and Richard, H.T. Assessment of fire toxicity of building insulation materials, *Energy and Buildings.* 2010, *43: 2-3*

[29] Teo, M.Y., Yeong, Y.H. and Lye S.W. Microwave moulding of expanded polystyrene foam with recycled material – *Journal of Materials Processing Technology*. 1997, 63: 514-518

[30] The Effects of Recycled Material Content on the Performance of Plastic Foam Cushioning, International Trade Center (UNCTAD/WTO), Packdata Factsheet No.34

[31] Vaou, V. and Panias, D. Thermal Insulating foamy geopolymers from perlite, *Minerals Engineering.* 2010, 23; 1146-1151

[32] Vilapana, F. and Karlsson, S. A Review: Quality concepts for the improved use of Recycled Polymeric Material, *Macromolecular Journal.* 2008, 293: 274-297