

## Properties of Recycled Plastics from HDPE Drinking Water Bottles

Sineenart Chariyachotilert\*, Naruekmon Koouodomrut and Wipada Rittisith

---

### ABSTRACT

The growing amount of plastic bottles have caused plastic waste problem in Thailand and elsewhere. In this paper the recycling of drinking water bottles made of HDPE was studied. Collected waste bottles were ground to small pieces and then mixed with virgin HDPE resin at the composition of 0, 20, 25, 40, and 50% recycled plastics. The effect of adding 0, 10, 20 and 30% (w/w) of calcium carbonate as plastic filler was also studied. The mixed compound was injection molded into dumbbell – shaped testing samples and tested for density, tensile strength and elongation. The result showed that increased recycled plastics significantly reduced density and tensile strength but increased elongation of tested samples. Addition of calcium carbonate also significantly decreased both tensile strength and elongation. The chosen quantity of recycled plastics in compounded mixture was 20% and calcium carbonate content of 10%. The recycled HDPE was utilized by injection molding into flowerpots or multi-purpose trays.

**Key words:** plastic bottles, drinking water bottles, recycled HDPE, calcium carbonate, injection molding process

### INTRODUCTION

High density polyethylene (HDPE) consists of essentially linear molecules of repeating ethylene units. Its density is 0.94-0.965 g/cc. It has a milky, translucent appearance and is usually used to make bottles for milk, drinking water, laundry products, cleaning and other household chemicals (Selke, 1997). During plastic converting processes, some kinds of additives are mixed with plastics to impart properties. Fillers are relatively cheap, solid inert substances that are added in fairly high percentages to plastics, paints, and paper to adjust volume, weight, costs, or technical performance (Zweifel, 2001). They are typically used to lower the cost of plastics. They also significantly increase rigidity and stiffness,

but decrease both impact and tensile strength. Filler concentration is commonly in the range of 10 to 50% by weight (Hernandez *et al.*, 2000). Calcium carbonate is the dominant filler, accounting for about 70% of the world filler consumption in plastics. Calcium carbonate is white, odorless and tasteless powder with a density of 2.71 g/cc and a Mohs scale of 3. It is used for polyvinyl chloride, polyethylene, polypropylene, silicone and polyacrylate (Zweifel, 2001).

Plastic packages have been alleged to cause public waste disposal problems because of their bulky nature and difficult degradation. Plastic packaging accounted for 4.3% of all waste generated in U.S.A. in 1997 (EPA, 1998). Recycling is defined by the EU Directive on Packaging and Packaging Waste (EC, 1994) as the

reprocessing in a production process of the waste materials for the original purpose or for other purposes including organic recycling but excluding energy recovery. It is the fastest growing and most promoted waste disposal method worldwide. A minimum of 15% by weight of each type of packaging material has been set as the United Kingdom target for recycling (Lomas and Rose, 1999). In U.S.A., post-consumer plastic recycling has increased from 234 million pounds in 1989 to over 1.5 billion pounds in 1999 (APC, 2000). HDPE was recycled with a rate of nearly 26% for unpigmented bottles and 10.8% for pigmented bottles in 1994 (Selke, 1997). Unpigmented HDPE bottles are valuable in recycling because they can be reprocessed into any color. The recycling rates of overall HDPE and PET bottles in the USA reached the highest number at 23.8 and 22.8%, respectively, in 1999 (APC, 2000). Recycled PET is made into fiber, strapping and new containers. Recycled HDPE is made into bottles for non-food products, plastic pipes, plastic lumber, film and injection molding products like flowerpots, garden products, toys and traffic cones (Selke, 1997).

Recycled materials often degrade in properties. Trivijitkasem *et al.* (1999) reported about 43-135% increase in % elongation of recycled LDPE films over natural films at 28°C and change in elasticity caused by contaminants in recycled film. Recycled plastics usually lose some strength because of previous manufacture processes. In practice, virgin plastic resins are mixed with those recycled to compensate with the loss. For example, motor oil bottles are usually a blend of recycled HDPE and virgin resin (Selke, 1997).

Drinking water in PET or HDPE plastic bottles have been successfully marketed recently in Thailand because of their sanitary quality and convenience for consumption. Discarded empty bottles have multiplied. PET waste bottles have been collected and recycled along with those used

for carbonated and green tea beverages. However, HDPE waste bottles are not much interesting for waste collectors because HDPE is low in cash value. The redemption prices are about 13 and 5 baht / kilogram for unpigmented and pigmented HDPE bottles respectively, and 18 baht / kilogram for PET bottles. Therefore, many HDPE empty bottles have gone through incineration or open dumping instead of recycling.

The purposes of this study were to examine the properties of recycled HDPE drinking water bottles, and the possibility of adding CaCO<sub>3</sub> filler to the recycling compound for cost reduction.

## MATERIALS AND METHODS

Empty HDPE drinking water bottles were collected from trashes in Kasetsart University. After cleaning, they were shredded by a plastic chopping machine into small pieces, about 15 mm<sup>2</sup> per piece. Chopped recycled plastics were compounded with virgin HDPE resins and CaCO<sub>3</sub> filler and made into dumbbell-shaped testing samples with dimensions of 12.5×50×4 mm (W×L×H) using the Battenfeld BA250CDC injection molding machine. The compositions of recycled HDPE were 0, 20, 25, 40, and 50%, while those of CaCO<sub>3</sub> filler were 0, 10, 20, and 30%. The samples were weighed with a Sartorius BP110S analytical balance and tested for tensile strength according to ASTM D 638M-91a using the Flounsfeld H50ks Universal testing machine. The experiments were done in 10 replicates. The sample made of virgin resin without CaCO<sub>3</sub> filler was used as a control.

The chosen composition of recycled HDPE filled with various levels of CaCO<sub>3</sub> was then utilized to make injection-molded products in the form of square-shaped trays with dimensions of 60×60×50 mm (W×L×H). A free fall drop test according to ASTM D2463 was conducted to trays at the level of 150 cm drop height. The experiments were done in 5 replicates.

The statistical analysis was done using ANOVA and Duncan's new multiple range test (DMRT).

## RESULTS AND DISCUSSION

### Physical properties of recycled HDPE

Waste HDPE drinking water bottles were compressible, translucent white in color, and possessed waxy finish. Their closures were snap-fit caps made of HDPE which could also be recycled. This was different from PET drinking water bottles containing PP screw-on caps which have to be separated before recycling. When mixing high percentage of inorganic  $\text{CaCO}_3$  powder to organic HDPE plastics, it was found that  $\text{CaCO}_3$  did not disperse uniformly and the mixture viscosity was high. Therefore, the maximum amount of  $\text{CaCO}_3$  filler was limited at 30% to avoid obstacles in injection of molten plastics during a molding process. The color of recycled HDPE with  $\text{CaCO}_3$  filler was changed to opaquely white. Its appearance became matte and non-compressible.

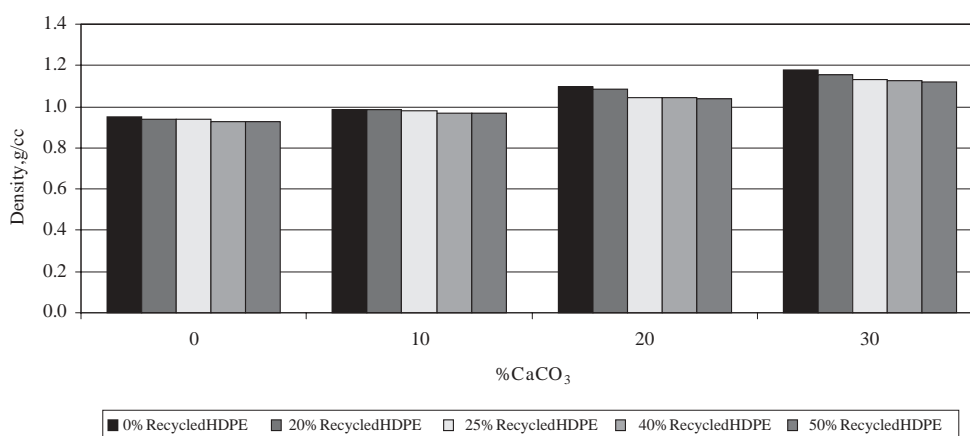
The density values of dumbbell samples were calculated from measured weight and volume values and shown in Figure 1. For every level of  $\text{CaCO}_3$ , the sample densities gradually decreased as the amount of recycled HDPE increased. Only slight variation of density was observed, probably

because other kinds of waste were eliminated before recycling, thus the major constituent of recycled plastics in this experiment was nearly all HDPE. On the contrary, as the amount of  $\text{CaCO}_3$  filler increased, the density of recycled HDPE increased significantly ( $p < 0.05$ ). Since the density of  $\text{CaCO}_3$  filler (2.71 g/cc) is much higher than that of natural HDPE (0.95 g/cc), the addition of  $\text{CaCO}_3$  filler would increase the mass and density of the compound (Zweifel, 2001). At 20 and 30%  $\text{CaCO}_3$ , the density of all HDPE samples, both virgin and recycled, were all greater than 1 g/cc.

### Mechanical properties of recycled HDPE

Figure 2, 3 and 4 showed the results from tensile strength tests for recycled plastics. The decreased density of recycled plastics caused the polymer weakness as shown in the extended elongation of samples with 25, 40, and 50% recycled content in Figure 2. The strain of recycled HDPE increased 28-198% over virgin resin as the amount of recycled HDPE increased from 25 to 50%. The result was agreeable to that of Trivijitkasem, *et al* (1999) which observed 43-135% increase in % elongation of recycled LDPE films over natural films at 28°C.

Tensile strength of recycled HDPE was reduced significantly ( $p < 0.05$ ) as the content of recycled plastic and  $\text{CaCO}_3$  filler increased



**Figure 1** Density of recycled HDPE with  $\text{CaCO}_3$  as filler.

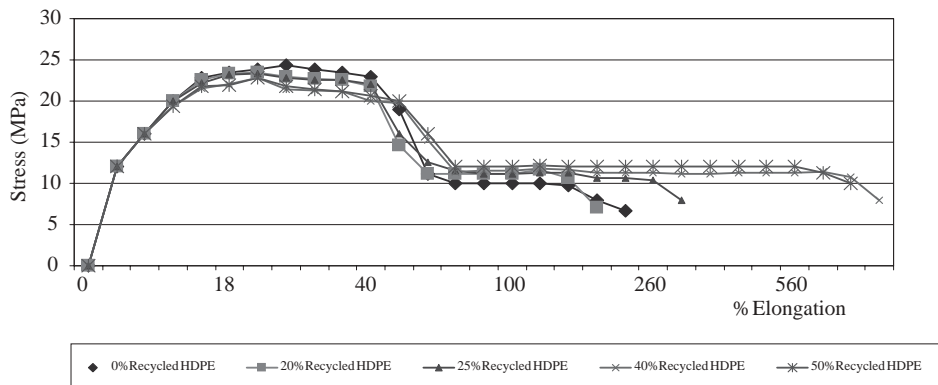


Figure 2 Stress strain curve of recycled HDPE without filler.

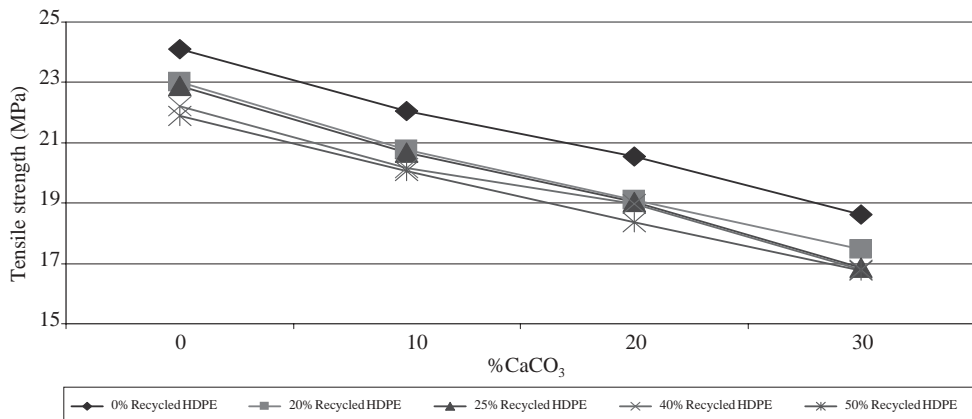


Figure 3 Tensile strength of recycled HDPE with CaCO<sub>3</sub> as filler.

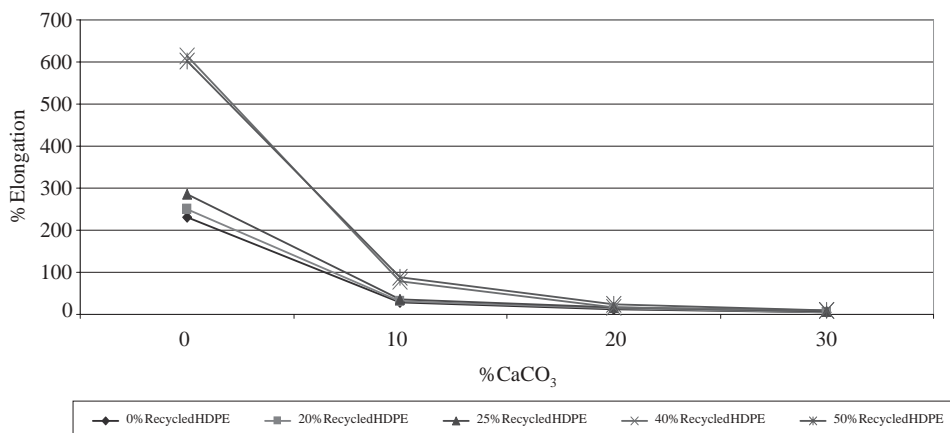


Figure 4 Elongation at break of recycled HDPE with CaCO<sub>3</sub> as filler.

(Figure 3). The decrease in strength was apparent for every recycled materials not just only plastics because some degree of degradation in molecular structure happened during previous processing methods. In practice, virgin resin was usually combined with recycled plastics to provide strength to recycled products such as motor oil bottles made of recycled HDPE in the USA (Selke, 1997). The effect of  $\text{CaCO}_3$  filler in tensile strength reduction of recycled plastics increased as the amount of  $\text{CaCO}_3$  filler increased from 10 to 30%.

The values of %elongation at break decreased significantly ( $p < 0.05$ ) as the percentage of  $\text{CaCO}_3$  filler increased (Figure 4). Sudden decreases were evident at 10%  $\text{CaCO}_3$  filler for all percentages of recycled HDPE. This was because  $\text{CaCO}_3$  filler with a Mohs scale of 3 imparted its hardness to recycled HDPE and made it stiffer and less elastic than virgin resin (Hernandez, *et al.*, 2000; Zweifel, 2001). Samples of 0 and 20% recycled HDPE exhibited nearly the same characteristic of decrease. In addition, samples of 40 and 50% recycled HDPE also followed the same decrease both qualitatively and quantitatively. Therefore, the composition of 20% recycled HDPE was chosen in this experiment to make recycled products having mechanical properties close to those of virgin resins.

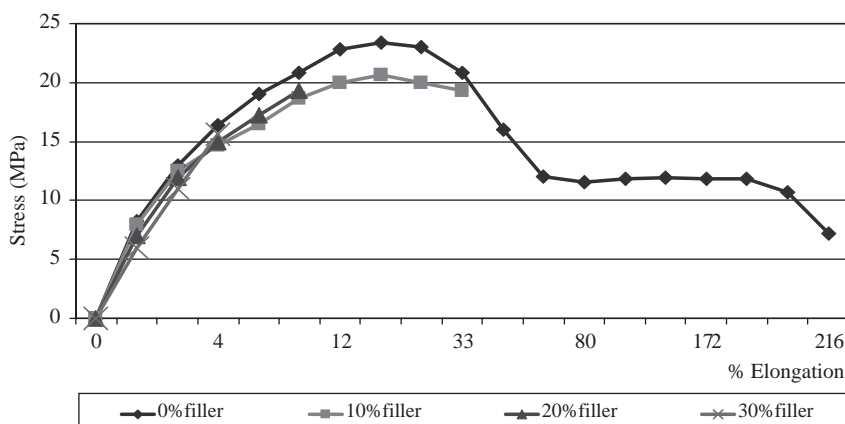
### Utilization of recycled HDPE

Figure 5 showed the stress strain curve of 20% recycled HDPE dumbbell samples with  $\text{CaCO}_3$  filler. The behavior of plastics was changed from flexible and high elongated at 0%  $\text{CaCO}_3$  filler to hard and brittle at 20 and 30%  $\text{CaCO}_3$  filler. This result was confirmed from the free fall drop test done 20 times per sample of square-shaped trays as shown in Table 1. The number of broken trays increased as the  $\text{CaCO}_3$  filler content increased over 10%. All tested trays broke at the height of 150 cm for 30%  $\text{CaCO}_3$  filler. Recycled products at 20 and 30%  $\text{CaCO}_3$  filler were not uniformly colored due to the difficult dispersion of inorganic  $\text{CaCO}_3$  filler in organic plastic matrix. Moreover, brittleness in recycled products could increase breakage risks during handling and distribution. Therefore, the content of  $\text{CaCO}_3$  filler was set at 10%.

**Table 1** Free-fall drop test of 5 trays made of 20% recycled HDPE with  $\text{CaCO}_3$  as filler.

% $\text{CaCO}_3$	Number of broken samples
0	1
10	1
20	2
30	5

Note: No statistical analysis



**Figure 5** Stress strain curve of recycled HDPE with  $\text{CaCO}_3$  as filler.

Recycled HDPE in this experiment was made into trays which could be used as flowerpots or multi-purpose containers. If other kinds of molds have been available, other recycled products could have been manufactured. In practice, HDPE has been commercially recycled into various products in U.S.A., such as lumber, motor oil bottles and traffic cones (Selke, 1997). Each product would require different composition of recycled plastics and possess different mechanical properties.

#### **Economy of recycled HDPE**

Recycling was intended to reduce valuable materials in waste stream as well as new raw materials from natural resources. It was desirable to recycle as much material as possible. However, the high amount of recycled materials degraded their mechanical properties. Therefore, the chosen composition for HDPE recycling in this research without suffering of product strength was 20% recycled HDPE and CaCO<sub>3</sub> filler should not exceed 10%.

From the local supplier information in Bangkok, the quoted prices of virgin HDPE resin and CaCO<sub>3</sub> filler during April to June, 2005, were about 53 and 1 baht per kilogram respectively, while the redemption value of unpigmented HDPE waste bottles for trash collectors was 13 baht per kilogram. Though the selling price of waste HDPE was not exactly available, it was certainly less than 53 baht per kilogram. The manufactures of HDPE products could save about 12% of the raw material cost if 20% recycled plastics was utilized. Moreover, if cheap CaCO<sub>3</sub> filler was also added to the compound, the saving was up to nearly 20%.

Therefore, potential in recycling of waste HDPE drinking bottles is good and should be promoted extensively. One way of promotion is setting the recycle rate as done in developed countries. The UK recycling target has been minimally set at 15% for every material (Lomas and Rose, 1999). The 23.8% recycling rate of HDPE in the USA in 1999 (APC, 2000) should be regarded as a good role model for recycling plans in Thailand.

#### **CONCLUSION**

Increase of the quantity of recycled HDPE significantly reduced density and tensile strength but increased elongation of the recycled compound. CaCO<sub>3</sub> filler also significantly decreased both tensile strength and elongation. The composition in compounded mixture was set at 20% recycled HDPE and 10% calcium carbonate in order to keep the mechanical properties of recycled products in close proximity to those of virgin resins. The addition of CaCO<sub>3</sub> filler had the potential to reduce the cost of plastic raw material.

#### **LITERATURE CITED**

- APC. 2000. **National Post-Consumer Plastics Recycling Study**. The American Plastics Council, Arlington.
- EC. 1994. **The Packaging Directive On Packaging and Packaging Waste (Directive 94/62/EC)**. Office of Official Publications of the European Communities, Brussel.
- EPA. 1998. **Characterization of Municipal Solid Waste in the United States: 1998 Update**. U.S. Environmental Protection Agency. Washington D.C.
- Hernandez, R., S. Selke and J. Culter. 2000. **Plastics Packaging: Properties, Processing, Applications and Regulations**. Hanser Publishers, Munich. 425 p.
- Lomas, O. and I. Rose. 1999. **Packaging Waste Recycling Obligations**. Pira, Leatherhead. 360 p.
- Selke, S. 1997. **Understanding Plastics Packaging Technology**. Hanser Publishers, Munich. 206 p.
- Trivijitkasem, S., M. Suthiopad and S. Sirininlakul. 1999. Thermal and Physical Properties of Recycled Plastic Film. **Kasetsart J. (Nat. Sci.)** 33 (1): 111-125.
- Zweifel, H. 2001. **Plastics Additives Handbook**. Hanser Publishers, Munich. 1148 p.