Advanced Performance Materials 5, 159–169 (1998)

Glastic Composite Prototypes: A Materials Alternative for Recycling Plastic and Glass Waste

STEPHANIE CARVALHO, L.E. MURR AND ROY M. ARROWOOD
Department of Metallurgical and Materials Engineering and Materials Research Institute, The University of Texas at El Paso, El Paso, TX 79968

Abstract. Multiple plastic compositions containing polyethylene, polystyrene, PVC, ABS, Nylon, polypropylene, with various particle morphologies and a narrow range of sizes and size distributions were mixed with similar size brown glass into "glastic" composites having glass compositions of 15, 30, and 45 wt%. These prototypes were molded in a form similar to standard clay bricks at 235°C and were compression tested to more than double the fracture stress of clay bricks at temperatures ranging from 20 to 50°C. These prototypes illustrate the prospects for utilizing waste plastics and glass in simple commercial materials applications and the relief of land fill problems which are now world-wide.

Keywords: plastic composites, waste recycling, glass mixtures

1. Introduction

The accumulation and disposal of waste—personal and industrial—is a national and international issue. There are limitations in landfill areas, and hydrological and geological problems associated with the areas and the waste stored. It is estimated that an American family of 4 discards over 5,000 pounds of trash in contrast to about 1,100 pounds of recycled materials: aluminum cans, glass containers, plastic bottles, steel cans, newspapers, and cardboard. One million tons of aluminum is recovered in the U.S. in contrast to nearly twice this amount discarded. Nearly two million tons of steel are recovered in contrast to five times this weight discarded. Nearly half the 52 million tons of paper are recycled each year. By contrast, only 2% of plastic waste is recycled. Nearly 80% of glass waste is unrecovered [1].

Recycling plastics poses the biggest materials recycling challenge in the U.S. Plastic recycling success is almost exclusively limited to soft-drink bottles made of polyethylene terephthalate (PET) which can be melted down and regenerated into a fibrous insulation used in jacket manufacture, car interiors, carpets, or remolded into new bottles [2]. The problem with plastics is that because they are often chemically different (in molecular structure and weight), they are not compatible when mixed, and there are no easy mechanisms or procedures to assure efficient, economical separation of the plethora of plastics discarded annually in the U.S.

While glass is somewhat more forgiving when "mixed", it is often much cheaper to recompose glass out of raw materials just as is the case for most plastic products, mostly fabricated by injection molding of virgin polymer.

Just as much of the "recycling" success with plastics uses the recovered waste to produce new products different from the original uses, so it is with glass and other waste materials. New York City has experimented with "Glasphalt" which mixes recycled (and crushed) glass bottles and asphalt. In effect, the glass substitutes for conventional rock materials to provide a matrix-filler. Many states now require at least 10% of highway materials mixtures to be shredded tires. Some success has also been achieved in mixing up to 20% flyash waste in aluminum which produces a relatively high-strength "composite" [3]. Such composite materials or nonreactive mixtures used for construction (a U.S. company called Waste Alternatives is experimenting with "plastic lumber"); highway pavements, and structural systems can have enormous potential for waste materials recycling, and keeping environmentally "inert" materials out of land fills, neighborhoods and warehouses.

While there have been a few attempts to produce useful mixtures of shredded plastics, glass, sand, and other wastes, including shredded tires [4, 5], none have been very successful. The successful development of materials mixtures—or composites—which are essentially independent of chemical reaction phenomena, hinges almost exclusively on the ability to physically bind the various surfaces together—creating effective adhesion within the mixture and its components. This in turn, is very dependent upon the nature of the mineral/polymer matrix interface and the sizes and distribution of sizes, as well as "shapes" of the individual constituents of the mixture (see figure 1). Successful mixtures from an engineering perspective are therefore uniformly adhering; consolidated. The mineral/polymer interfaces and the size, shape, and distribution features are important in the manufacture of many products since these features determine initial packing densities (often referred to as "green" densities) and packing configurations, porosities, etc. which ultimately control consolidation, and the product integrity [6].

The research to be reported on this paper represents a very preliminary effort to develop a plastic and glass ("glastic") waste composite prototype with simple commercial applications. This "glastic" composite prototype consists of a mixture of eight coarse, polymeric powders, and three different weight proportions of coarse-ground waste glass: 15%, 30%, and 45%. These prototypes have been prepared in similar form to commercial clay bricks which are used as a standard of reference.

The strategy of this research was to eliminate the cost of sorting individual polymers from the waste stream, by molding unsorted thermoplastic waste (with added glass). This approach mandates that applications of the product should not require high tensile strength. Applications such as brick veneer for residential construction, curtain walls, or patio and landscaping pavers would meet this requirement.

Because of the incompatibility of randomly mixed polymers under injection molding conditions and the risk of contamination of waste material feedstock with foreign matter that could cause downtime or damage in complex molding machinery, a simple and robust press-molding approach was used here. Large savings in capital investment would be an additional benefit of this stratagem. The equipment is quite simple and could be made in even a rudimentary machine shop from readily available components.

This paper describes the method developed for producing bricks of glass and unsorted thermoplastics, and reports the stress-strain behavior of the consolidated material.

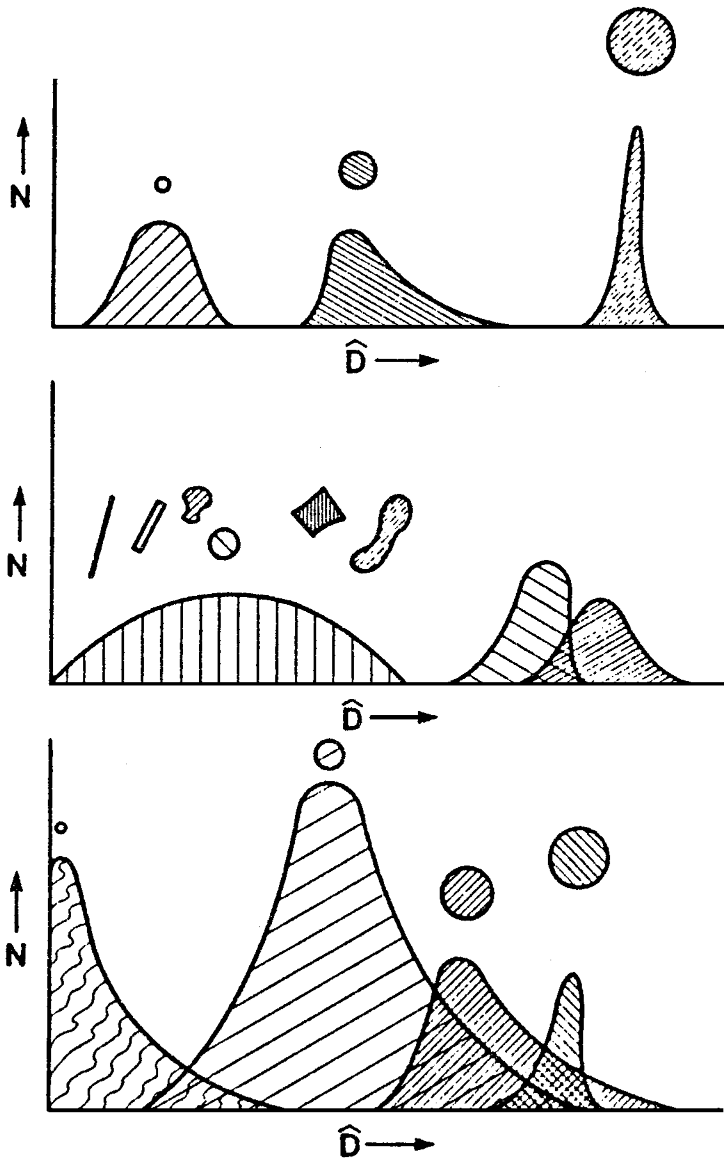

Figure 1. Schematic representations of materials or powder mixtures having different particle morphologies, mean sizes *D*, and particle size distributions.

2. Experimental details

An experimental polymer mixture composed of eight different, raw polymers (plastics) was composed as illustrated in Table 1 along with the details for brown glass additions. This

Table 1. Plastic composition-standard properties.

Polymer	Melting or glass transition temperature (T_M or T_G)	Particle size range (cm)	Percentage of standard composition	Density (cm^3)
Polypropylene	$T_M = 170°C$	0.12–0.85	7.0	6.90–0.91
Black PVC	$T_G = 100°C$	0.16–0.96	14.4	1.49–1.58
Brown PVC	$T_G = 100°C$	0.36–0.48	14.4	1.49–1.58
ABS	$T_M = 120°C$	6.32–0.32	4.8	1.05–1.07
Polystyrene	$T_G = 105°C$	0.08–1.20	15.0	1.1
Polyethylene (low density)	$T_M = 98–115°C$	0.40–0.48	25.4	0.92–0.93
Nylon (polyamide)	$T_G = 190–225°C$	0.16–0.32	2.7	1.13–1.15
Polyethylene (high density)	$T_M = 126–136°C$	0.46–0.48	16.3	0.95–0.96

composition approximates the ratios of national annual production rates of the constituent thermoplastics and therefore is expected to be roughly similar to the average composition of unsorted thermoplastics in municipal waste. Table 1 also shows particle size variances (extremes). Figure 2 illustrates these plastic and glass components for comparison. It can be noted in figure 2 and Table 1 that there is not a particularly wide particle size variance in the development of this prototype in contrast to the possibilities illustrated schematically in figure 1. One reason for this concept was the simplicity in standardizing future crushing or shredding methodologies for actual waste streams containing plastics or plastic and glass mixtures. The plastic mixture shown in Table 1 constitutes what was designated a "standard mixture" in the prototype development to be described herein. Three different glass fractions were added to the standard plastic mixture (Table 1): 15%, 30%, and 45% by weight. The corresponding glass size ranged from 0.1 to 0.48 cm.

Figure 3 shows the aluminum mold configuration which was used to prepare prototype "glastic" bricks having dimensions approximating those of standard (American) clay bricks (nominally 20 cm $\times$ 10 cm $\times$ 5 cm).

Bricks were molded from stirred mixtures heated to 235°C for up to 0.3 h to produce a taffy-like consistency. Preheating was accomplished by tumbling the mixed plastic beads and shred (sufficient for molding one brick) in an externally heated drum, rotating at 30 rpm about its cylinder axis, which was inclined at 30° from the horizontal. The drum was made from a 39 ounce coffee can (about 15 cm in diameter by 17 cm tall), coated on the outside with black high-temperature paint and sprayed on the inside before each use with a silicone mold release which was dried thoroughly before use. The outside of the drum was heated by four 250 W infrared heat lamps. A polyisocyanurate foam lid reduced heat loss at the mouth of the can. Heating took 20 minutes, with hand stirring every 5 minutes. The preheated mass was at a temperature of about 235°C. A preselected, heated volume of the composite mixture was placed in the mold shown in figure 3 and compressed rapidly to 3.2 ksi (22 MN/m^2), then slowly to 4.5 ksi (31 MN/m^2), held steady for 2 to 3 minutes and then reduced to 3.2 ksi (22 MN/m^2) for a final dwell of 2 minutes. After this molding cycle of about 6 minutes, the brick was removed from the mold and allowed to cool. A range of

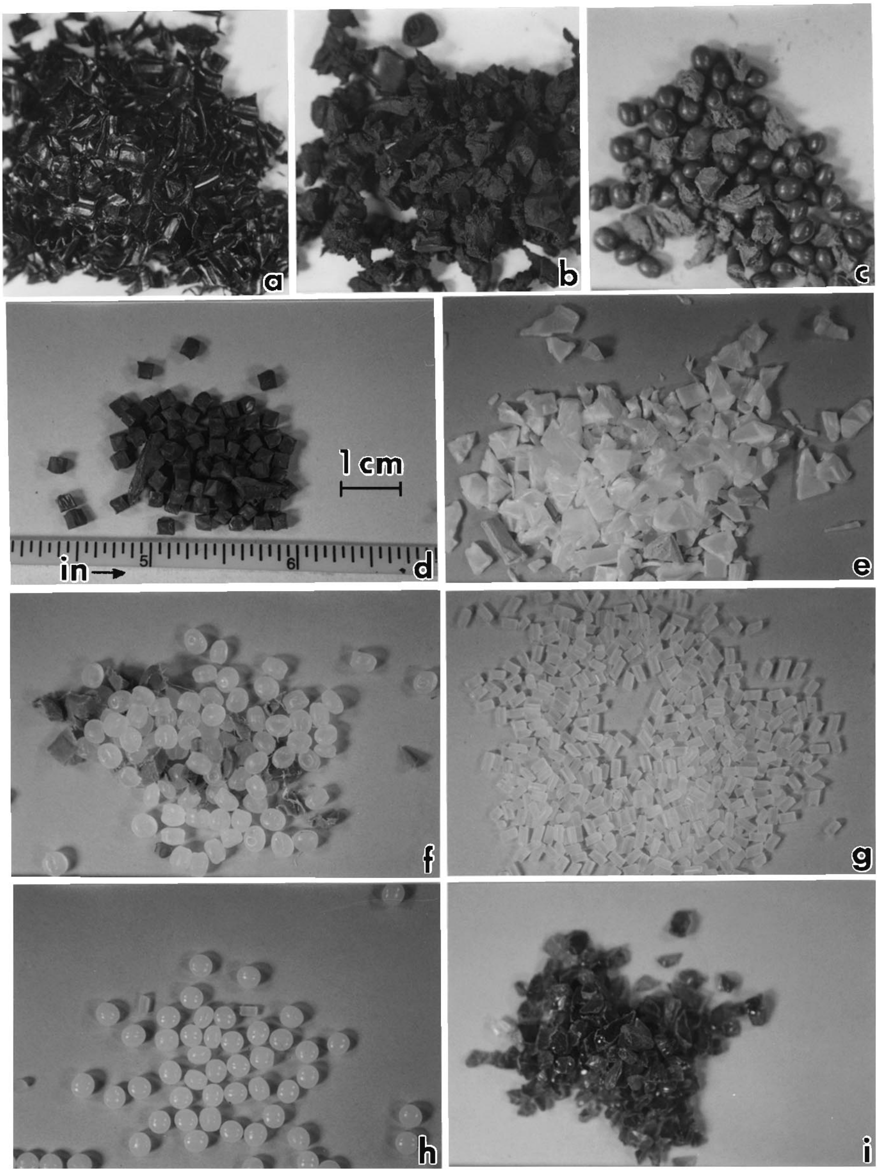

Figure 2. Glastic composite components: (a) polypropylene, (b) black PVC (6708, 60 durameter), (c) brown PVC (2000, 70 durameter), (d) ABS, (e) polystyrene, (f) low-density polyethylene, (g) nylon, (h) high-density polyethylene, (i) brown glass. Magnification (scale) for all components given in (d).

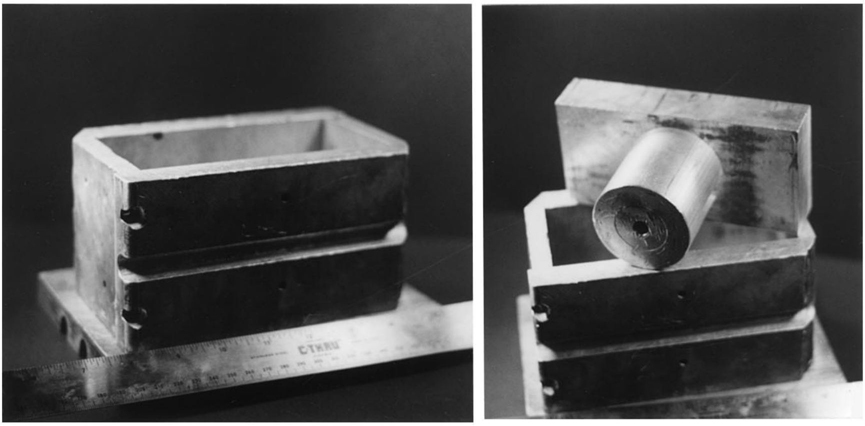

Figure 3. Aluminum mold (left) and mold with top (right).

temperatures was explored in order to develop the best mold mixture at the lowest temperature. The best mold mixture was characterized as the best bonding of the final composite brick which did not crumble or fail profusely at the maximum compressive test stresses at 20°C.

Molded "glastic" bricks were cut into square sections measuring 7.6 cm on a side through the thickness and compression tested over their full surface in a Tinius-Olsen tensile machine. Compression testing was also performed on same size clay and concrete brick sections for comparison. Testing was done at three test temperatures: 20°C, 40°C, and 50°C. Load testing was conducted to a total compression of 0.22 cm.

3. Results and discussion

Figure 4 shows the appearance of a typical molded, "glastic" brick with no glass (only the standard plastic mixture). Figure 5 shows for comparison compression-tested side views of brick sections containing 15% and 45% (by weight) glass. The lower glass fraction generally outperformed the higher glass fractions, and all composition prototypes outperformed standard clay bricks in compression tests as illustrated in the comparative data illustrated in figure 6 for each of the three glass compositions, and compression test temperatures. Figure 7 shows the complete comparison of the experimental prototype data, illustrating the best product performance to be the 15% (by weight) glass brick at essentially room temperature (20°C).

While the 15% glass-plastic mixture composition prototype seems to be the best product, all prototype compositions outperformed standard clay bricks in compression testing and failure performance.

It is unlikely that the prototype glastic bricks developed and examined in this study would be considered an alternative or substitute for structural applications of clay bricks. In addition, it is unlikely, because of environmental considerations, and other practical considerations, that bricks pressed from unsorted plastic waste material would find indoor uses.

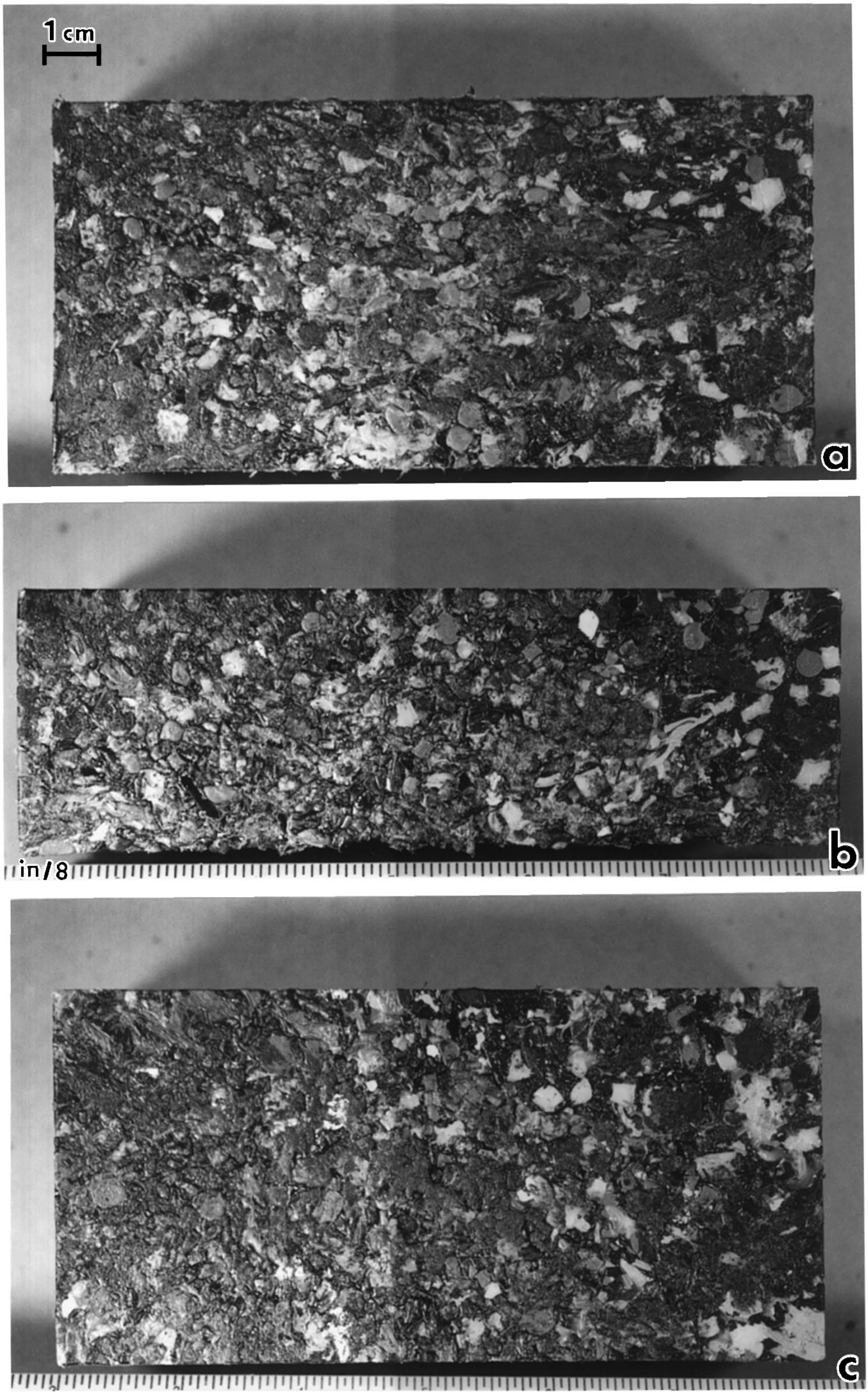

Figure 4. Standard plastic composition brick (Table 1) with no glass additions. Top (a), side (b), and bottom (c) views are shown (scale shown in (a)).

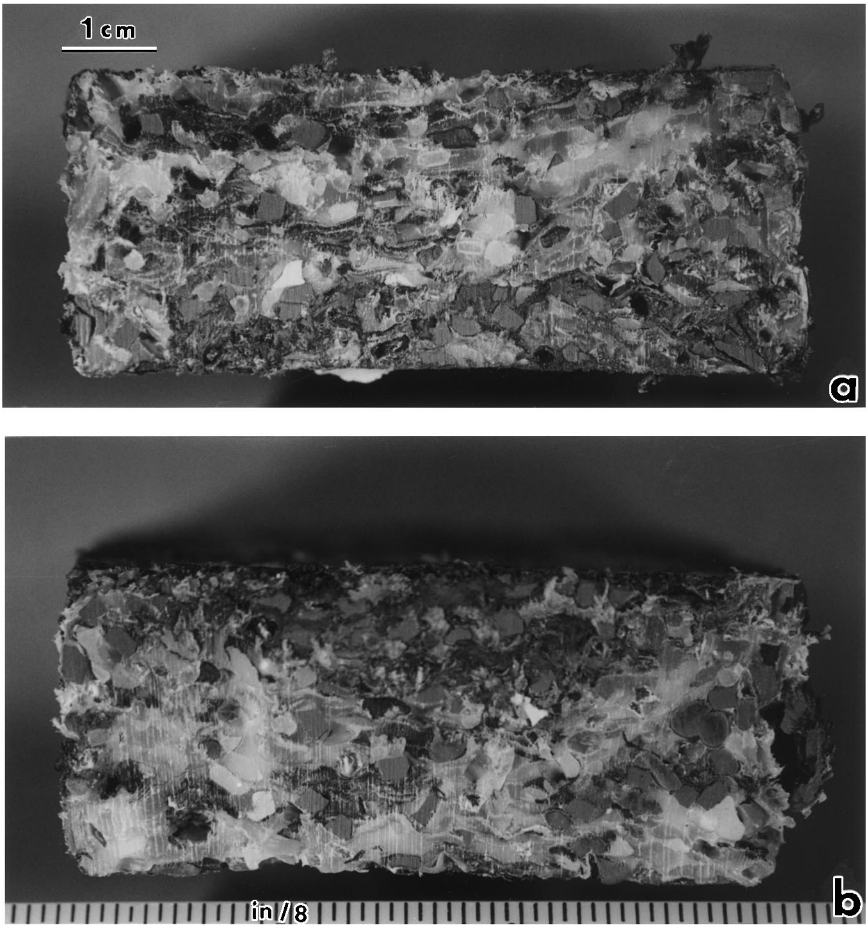

Figure 5. Sections of glastic composite brick (a) 15% glass composition compressed at 20°C, (b) 45% glass composition compressed at 20°C (scale shown in (a)).

However, simple outdoor applications involving walkways, patios, etc. utilizing interlocking patterns which would not require adhesives, etc. would be well served, and would even be attractive. Furthermore, since the maximum fabrication temperature is around 235°C, simple solar heating devices (reflectors and concentrators) would be well suited to preparation of the mixtures for introduction into molds. The fact that these prototypes seem to accommodate the unsorted plastic mixtures of thermosetting plastics and thermoplastics would seem to be an attractive advantage.

The simple preheating and press-molding procedures demonstrated here require little capital investment. Capital cost savings could be critical in making bricks and similar products that could compete in the cost-sensitive housing/landscaping market. In addition, this low-technology approach might permit small businesses to seize this opportunity. A

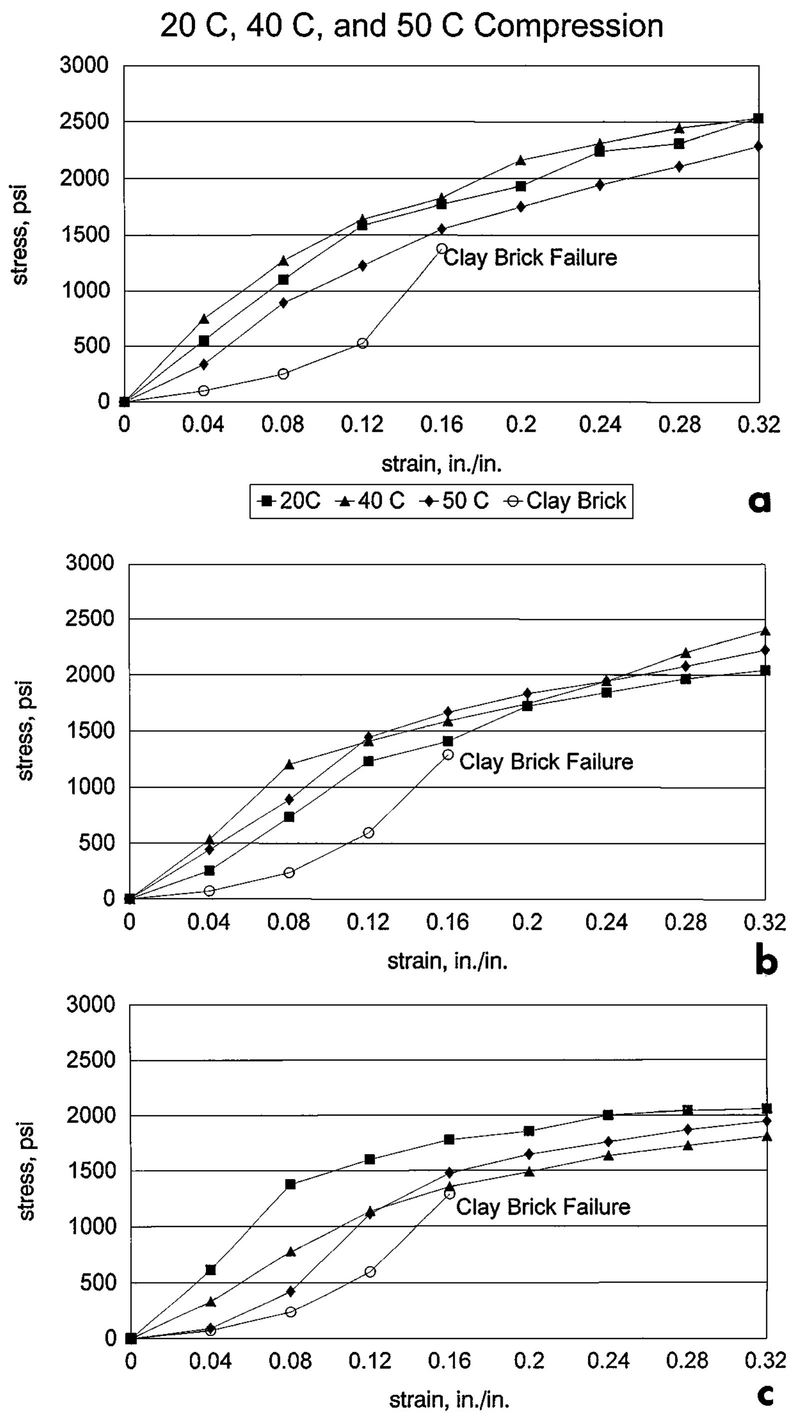

Figure 6. Compression stress-strain diagrams comparing the performance of glastic composite bricks with standard clay brick. Units are in psi for convenience (1 psi = 6.89×10^3 Pa).

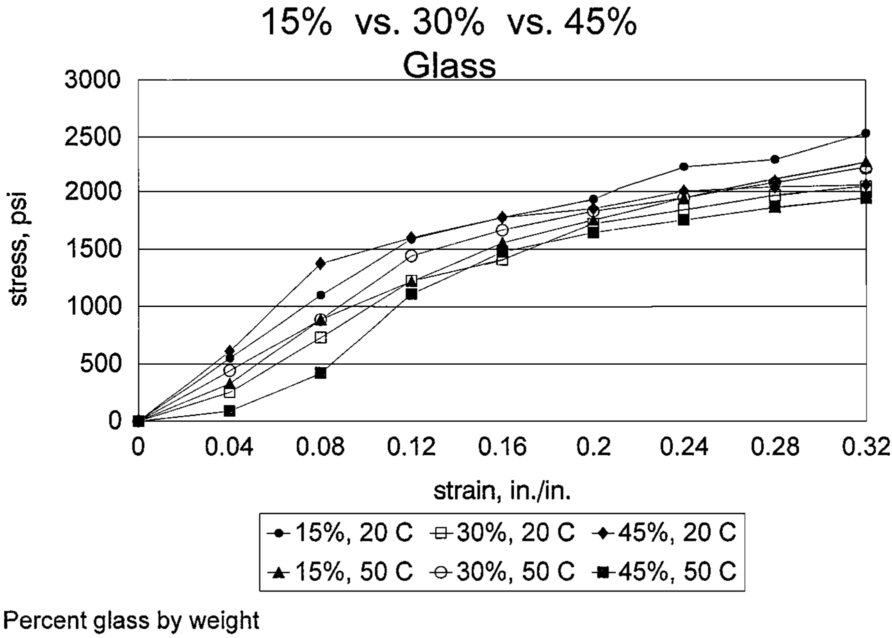

Figure 7. Compression stress-strain diagrams comparing the performance of standard glastic composite bricks at 20°C and 50°C test temperatures. Units are in psi for convenience (1 psi = 6.89×10^3 Pa).

particular opportunity may lie in the USA-Mexico border regions, where a huge, modern injection-molding industry thrives alongside numerous, small and primitive clay brick plants. On the Mexican side of the El Paso (Texas)/Ciudad Juarez (Mexico) metroplex, for example, there are more than two hundred small, family-operated plants which produce low-fired, low-strength clay bricks. Some of these labor-intensive enterprises might benefit from the manufacture of glastic bricks.

These experiments have shown that low-technology molding of unsorted thermoplastic waste is technically feasible, producing acceptably strong material for lightly stressed architectural uses. The major impediment to practical implementation of this concept may be the cost of shredding equipment for the waste, but this cost is much less than the capital requirements for an injection-molding plant.

One of the strategies driving the establishment of the component particle sizes and size distributions (which were somewhat limited) was a consideration of the actual shredding or pulverizing process required to develop appropriate raw waste plastics and mixtures from actual waste streams. The primary considerations involve the ability to shred or pulverize, these processes improving dramatically with reductions in processing or waste stream temperatures. In addition, small size particles require more energy and process control, and there were few observed advantages of wide ranges of particle sizes to fill interstices, etc. The maximum advantage for these prototypes seemed to occur for similar size particles; especially in the context of the maximum bonding or integrity achieved by the prototypes at the maximum process temperature (235°C).

In the context of figure 1, the development of requisite particle geometry or size distributions could pose a formidable set of experimental variables. However, as demonstrated in this very preliminary study, this issue may not be as important as the necessary conditions to shred or pulverize the raw plastic feedstock necessary to create simple composite products. In addition, there are other simple and larger product configurations and even simpler processing features such as a reduction in the molding pressures, etc.

Additions of glastic compositions or mixtures as discussed in this preliminary research might also be explored in the development of highway compositions, i.e., additions to asphaltic preparations where requisite temperatures would create necessary bonding. It is possible that "glastic" mixtures combined with up to 10 wt% shredded tires with asphaltic compositions could produce unique, long-wearing, and long-lasting applications for glass and plastic waste streams. Such prospects for alternative materials are certainly more sensible than simply taxing land fills with essentially inert waste.

4. Summary and conclusions

A novel "glastic" composite prototype brick product has been developed consisting of a similar-sized plastic mixture and compositions (by weight) of glass. The plastic mixture consists of eight different polymers. The "glastic" composite prototype materials all outperformed standard clay bricks in compression strength testing, although this prototype is not envisioned as a substitute for commercial brick in construction applications. These composite prototypes demonstrate the potential for utilizing plastic and glass waste mixtures in other novel systems such as highway materials compositions which could include asphaltic based compositions including shredded rubber. The potential applications of such materials systems should receive more attention as alternatives to the extraordinary land fill problems world-wide.

Acknowledgments

This research was supported in part by a Mr. and Mrs. Maclntosh Murchison endowment. We thank M&Q Plastic Products of El Paso, TX for donations of surplus and regrind plastics. We are also grateful to Shane Andrews, Ana Campuzano-Contreras, Robert Patton, and Lourdes Dominguez who initiated aspects of this research.

References

1. N. Grove, Recycling, National Geographic **186**(1), 92 (1994).
2. V.S. Rebeiz, D.W. Fowler, and D.C. Paul, Overview of polymer composites using recycled PET, Polymers and Polymer Composites, **1**(1), 27–35 (1993).
3. P.K. Rohatgi, Low-cost-fly-ash-containing aluminum-matrix composites, JOM, 55–59 (1994).
4. B.J. Jody, E. Daniels, P. Bonsignore, and M. Brookmeier, Recovering recyclable materials from shredder residue, JOM, 40–43 (1994).
5. E. Daniels, B. Jody, and P. Bonsignore, Alternatives for recycling auto shredder residue, J. Resource Management and Technol. **20**(4), 14 (1992).
6. R. German, *Particle Packing Characteristics, Metal Powder and Industry Federation* (Princeton, NJ, 1989).