2. Manufacture of Plastic Lumber Using Mixed Plastics

The manufacture of flow molded linear profiles, or plastic lumber as it is commonly referred to, has received a great deal of attention as a solution to using mixed plastics because minimal separation of the mixed plastic is necessary to produce this type of product. It is viewed as a method to utilize plastic containers and films en masse which could not otherwise be collected in significant quantity to justify separation. Plastic lumber is also viewed as a method to utilize "tailings," the miscellaneous plastics left after a recycle stream has been "mined" of higher value HDPE and PET bottles. Tailings may also typically be the plastics collected by recycling that were not asked for. Although, from a polymer science point of view, such a diverse combination of plastics is not considered to be readily capable of "blending" into a compatible product, the mixture can easily be processed into large cross-section items that have significant strength and utility [Nosker et al., 1990].

Although the manufacture of plastic lumber from mixed plastics without separation (theoretically) has large potential as a solution to mixed plastics in general, there are associated problems. Depending on market prices and proximity to the manufacturer, it may be necessary to pay a manufacturer to take the waste plastic (there are no mixed plastic lumber producers in Illinois). The cost of shipping can have a large impact on the recycling operation economics. As a result, there are plastic lumber startup companies in progress in Illinois, and Amoco Chemical Company has provided funding to the Center for Neighborhood Technology in Chicago to study and solicit proposals for a mixed plastic recycling plant in the Chicago area [CNT, 1990]. It may also be necessary to separate plastics to obtain a desired color or appearance of the finished lumber product, or to attain a product with reasonable quality standards. While dark browns, blacks and grays are possible with mixed plastic bales, lighter colors such as blue, yellow and light gray are not possible without using separated clear and white HDPE/LDPE. A large proportion of LDPE, both granulated and molded, produces articles which are very elastic. Similarly, a large proportion of PP will produce articles which are brittle. Consequently, blending of granulated material by plastic type may be important depending on the product to be manufactured. If separated with enough quality control, the separated plastics will bring a better price through some other market. The manufacturer may require that a municipality collecting mixed plastics buy the product following recycling.

2.1 Plastic Wood Producers

There are approximately 9 companies currently producing lumber from mixed plastic collection programs, and more companies are reported to be starting up. Three are in the Midwest region: American Plastics Recycling Group (Ionia, MI), Hammer's Plastic Recycling (Iowa Falls, IA) and The Plastic Lumber Company (Akron, OH). The primary manufacturers, including those which take industrial scrap are listed in Table 2.1. Plastic lumber producers which take only HDPE are not listed. As can be seen, some plastic lumber manufacturers have certain conditions or require a certain amount of cleaning beforehand. It should be noted there are also plastic lumber manufacturers which produce only from higher grade recycle stock of natural and colored HDPE bottles which are not shown in Table 2.1.

2.2 Plastic Wood Production

A brief summary of some of the plastic lumber processing methods and the manufacturers in the field follows.

Some of the companies listed in Table 2.1 have developed a proprietary machine for production, while others have purchased the commercially available ET-1 machine manufactured by Advanced Recycling Technologies, Ltd of Belgium. All fabrication processes by the producers shown in Table 2.1 are generally similar and capable of producing thick-wall moldings (park bench pieces and pallets, for example) and profile extrusion pieces (long, straight, thick, heavy, lumber like products). The ET-1 machine accepts any type post-consumer plastic (see section 2.3). Rigid plastic containers must be ground to a 1/4" flake or chip, and film plastics or thin sheet plastics must be densified into small granules to maintain friction in the extruder [Mackzo, 1990]. The regrind and granules are then blended, during which additives and colorants may be added. In addition to post-consumer plastics as a source, packaging scrap, automotive and electrical scrap are cited as potential sources of feedstock.

The ET-1 machine consists of an extruder, molding unit, part extractor and controls. The extruder consists of a short, adiabatic screw rotating at high RPM for melting. The machine is designed to develop thorough mixing of material and to prevent degradation of plastics which are sensitive to heat by providing for a short melt history. The extruder operates at melt temperatures of 360 to 400°F. The temperature is regulated by external cooling, RPM adjustment, or barrel tolerance. Higher melt plastics such as PET and PC, and contaminants such as aluminum and copper become a filler in the melted resins. The molding unit consists of linear molds mounted on a turret that rotate through a

Table 2.1 Mixed Plastic Lumber Manufacturers

Company	Address	Plastic Accepted	Comments
American Plastics Recycling Group	P.O. Box 68 Ionia, MI 48846 (616) 527-6677	65% post-consumer 35% industrial scrap	All rigid plastic containers; accepts films separated out and separated clear and colored HDPE; will accept mixed bales if HDPE bales go to them also, but not alone
Hammer's Plastic Recycling Corp.	RR 3, Box 182 Iowa Falls, IA 50126 (515) 648-5073	60% post-commercial 20% industrial scrap 20% post-consumer	All rigid plastic containers; reluctant to accept film unless separated from rest; community must take product fabricated back; mixed plastic may have to be separated for product
Innovative Plastic Products	P.O. Box 898 Greensboro, GA 30642 (404) 453-7552	Industrial scrap	Accepts only packaging and film scrap from industry; full start-up in early 1991
National Waste Technologies	67 Wall St. New York, NY 10005 (212) 323-8045	99% post-consumer	
The Plastic Lumber Co.	209 S. Main Akron, OH 44308 (216) 762-8988	post-consumer industrial scrap post-commercial	HDPE rigid plastics and LDPE films separated, washed and ground
Plastic Recyclers	58 Brook St. Bayshore, NY 11706 (516) 666-8700	50% post-consumer 50% industrial scrap	
Superwood Ontario	2430 Lucknow, Mississauga, ONT, CA Unit #1 5S1V3 (416) 672-3008	90+% post-consumer 10% industrial scrap	Any plastic accepted; containers and films should be washed out and rinsed; no separation is necessary; future suppliers may have to buy product back
Superwood Alabama	P.O. Box 2399 Selma, AL 36702-2399 (205) 874-3781	40% post-consumer 60% industrial scrap	Accepts separated clear and colored HDPE, and PP (must be separated); separated out films also accepted
Polymerix/ Trimax Plastic Lumber	#4 Frasetto Way Lincoln Park, NJ 07035 (516) 471-7777	85% post-consumer 15% post-commercial	Accepts mixed plastic and/or HDPE, depending on production level and influx from existing accounts

water cooling tank. The extraction unit ejects air from the open end of the mold as it cools and then ejects the part onto an open shelf for removal. The mechanical properties of the resulting lumber (from tailings) are shown in Table 2.2. The mechanical properties of the product from unwashed mixtures are reported to be remarkably consistent even though variations in material collected affect feedstock composition [Renfree et al, 1989]. Capacity of the machines are 300 to 500 pounds/hour.

Table 2.2 Mechanical Properties of Plastic Lumber Profiles [Phillips, et al., 1989, Carrier, 1989]

Testing Group	Composition	Specific Gravity	Compressive Modulus (psi)	Yield Stress (psi) (@2% offset)	Compressive Strength (psi) (@10% strain)
CPRR [a]	100% tailings	0.931	89,600	2,707	3,167
CPRR	PE/heavily plasticized PVC and wire fragments/cable scrap	1.12	35,000	675	1,500
CPRR	50% milk bottles 50% densified PS	0.806	164,000	4,100	4,120 (@ 4%)
Innovative Plastic Prod.[b]	Mostly PE	-	66,000	-	5,800

a. Rutgers University Center for Plastics Recycling Research (CPRR).
b. Innovative Plastic Products additionally reports the following properties: Izod impact strength=105 ft-lbs./inch; tensile strength=2,350 psi; flexural strength=1,950 psi; coefficient of thermal expansion=6.94 x 10-5 in./in./°F.

Another of the plastic lumber manufacturers, Superwood Holdings PLC, licenses its patented process. There is currently one Superwood plant in Canada and another being started in Alabama. The process machinery was developed in Holland and is known as the Klobbie Process. Although HDPE, LDPE and PP are the primary raw materials for plastic lumber production, PET and ABS are allowed but controlled. Due to the fact that PVC will degrade and produce a poor product if present in a mix as a high proportion, it may only be present in small amounts without special additives being added. If a separate source of PVC is available, it can be used at a lower temperature by itself to produce a quality lumber product. Examples of plastic sources for the Superwood process are manufacturers of

plastic articles (films, bags, tableware, toys, trays, various domestic articles), scrap from beverage companies, milk suppliers, packagers, below standard products from production facilities and substandard resin pellets from plastic processors. Once collected and separated (for higher added value products), the plastics are blended together in horizontal mixers for a homogeneous mix, conveyed over a magnetic separator and sent to the extruder. A force feed drive may be used to feed the extruder with low density material such as film.

The Klobbie process for Superwood is similar to other mixed plastic lumber methods. Its primary component is the extruder (a large steel screw in a barrel driven at an RPM sufficient to cause friction to melt the resin mix). The plasticized material is forced out through an orifice into a steel mold. The addition of blowing agents and/or fillers vary the characteristics in the end product. The process then changes from extrusion to flow molding. Ten molds of similar or different cross-section but of the same length are mounted horizontally on a carousel in a tank of water. The molds rotate about a horizontal axis and at top dead center each mold is filled by the extruder. The other molds are cooled under water while the top mold is filled and, after being cooled, ejected pneumatically. The water is in a closed system and cooled by a chiller. Additional description of the process may be found in Mulligan, 1989 and Curlee, 1986.

The two Superwood plants in Alabama and Canada are equipped with one machine each, capable of handling 400 pounds/hour. Required capital investment is listed at $2 million per plant [PRU, 1990]. Labor requirements for the Superwood machines are listed as an operator with one to two assistants for the actual machine, two to three personnel for sorting and granulating per machine, and additional help for fabrication of finished products depending on the type of business and the product made [Mulligan, 1989].

The patented Hammer's Plastic Recycling process from Iowa is not sold, but rather operated as a joint venture. The process accepts post-consumer plastics and industrial/commercial scrap discards. A typical blended mixture of plastic prepared for final processing is 65% LDPE, 20% HDPE, 5% PP, 5% PET and 5% miscellaneous. The extrusion machine consists of a fill sensing device, heated extrusion nozzle, screen apparatus and an automatic sprue cutting device [Hammer, 1989]. Closed molds are filled under pressure ranging from 100 psi to 600 psi. Machine throughput is 800 - 1,000 pounds/hour.

Polymerix, a company which produces plastic lumber directly intended to compete with chemically treated outdoor grade lumber, has established a wash/clean process to obtain higher quality plastic with less foreign matter for input to fabrication. The result of material cleaning and partial separation prior to use is a product with mechanical properties

similar to wood and better than unprocessed plastic lumber (discussed in section 2.5). A wastewater treatment system for the wash process has been developed for a Polymerix lumber plant. It includes a fixed film upflow biological reactor and UV sterilization.

2.3 General Guidelines for Plastic Lumber Manufacturing

The Advance Recycling Technology ET-1 machine handles a wide variety of thermoplastics, although there are limitations due to the process and specific resin properties, as with the Superwood machine. The following guidelines for the most popular plastics have been submitted by the U.S. supplier of the ET-1 [Mackzo, 1990]:

- *LDPE or LLDPE* A good material for use in the process. However, LDPE is relatively soft and products containing too much of it may be insufficiently rigid for some applications, particularly in thin sections. It should be mixed with stiffer materials such as HDPE or PP.

- *HDPE* A good material for use in the process. HDPE is stiff and its mixtures with LDPE give a range of stiffness that cover most product requirements. Much of the HDPE on the market is copolymer material, but this is of no consequence to the recycler because for recycling purposes its performance is very similar to to that of a homopolymer.

- *PP* A good material for use in the process. It is relatively stiff and its mixtures with LDPE cover most of the range of stiffness requirements. However, the use of more than 30% by weight homopolymer PP is not advised because it is brittle at low temperatures and difficult to nail.

- *PVC* When finely ground and well homogenized PVC can be recycled on the ET-1. It can be mixed with other thermoplastics up to 50% by weight. Post-consumer plastic typically contains 5% PVC or less.

- *PS* Up to 40% by weight of this material can be mixed in. Impact grades add toughness to the mix. Non-impact PS (crystal) tends to cause surface finish problems. Expanded PS (EPS) should be avoided as a foam because of its low bulk density. Testing shows considerable strength improvements at 10 to 40% levels of densified EPS.

- *ABS* A good material for use in the process. The ABS family of resins combines rubbery and plastic properties and is extremely tough. ABS plastics are not broadly available.

- *Nylon* A wide variety are currently on the market. The most common, nylon 6 and 6/6 can be an additive at up to 10% by weight because they impart stiffness to an otherwise soft compound. Textile nylon scrap is usually nylon 6 or 6/6. Nylon 6 castings are suitable. Nylons 11 and 12 are even more suitable, but generally not available.

- *PET* Although its 500°F melt temperature is above the normal range of the ET-1, up to 15% can be mixed in if finely ground and carefully blended. PET beverage bottles, with HDPE base cup, labels and

aluminum caps have been run at 100%, but the product is brittle due to crystallization caused by slow cooling of thick sections and degradation of the polymer caused by moisture content.

2.4 Products From Mixed Plastic Lumber

Plastic lumber, as may be expected, has limited applications and use. It costs more than similar outdoor grade products/lumber and is therefore harder to sell, but offers superior resistance to degradation and weathering outdoors. There are transportation, industrial, marine and agricultural applications for plastic lumber products. Such products are generally not yet sold at a consumer level. A number of markets for plastic lumber products are tied to the activities of state and municipal agencies. The following marketplaces are estimated to have the most potential:

- Marine - docks, pilings, seawalls
- Industry - pallets sold directly to end users
- Local authority - transportation/road related markets and barriers, recreational area furniture and pilings
- Agriculture - stakes, electric fenceposts and confinements sold directly by cooperatives
- Fencing contractors
- Public utilities - water, sewage and telephone markers, underground cable covers
- Builder suppliers and garden nurseries - 'do-it-yourself' fencing and stakes

2.5 Enhancement of Plastic Wood Properties

The Center for Plastics Recycling Research at Rutgers has examined uses for plastics tailings (leftovers from recycling after the primary constituents of clear HDPE bottles and PET bottles have been recovered). A significantly greater market exists for the above mentioned separated HDPE and PET beverage bottles than in mixed form, and therefore their recovery may make economic sense. The researchers in New Jersey also have found that 20% of the plastic collected can be tailings material.

It was felt that PS could enhance the properties of lumber product made from tailings which were characterized as largely polyethylenes (HDPE or LDPE). The addition of densified reground PS to the mixture significantly improved the mechanical properties of the resulting product. Mechanical property test results of various additions of PS are shown in Table 2.3. It shows that addition of 10% by weight PS increased modulus of

elasticity 60%, yield strength by 15% and compressive strength by 2%. A straight line fit of the data shows that compressive and yield stress increase approximately 15% and 20%, respectively, for each 10% increase in PS up to 50% by weight. Above 35% PS, the modulus of elasticity decreased slightly and appeared to level off around 220,000 psi. A possible explanation for the significant increase in properties of the base material is that PS, which is a glossy polymer at room temperature, reinforces the largely polyolefin matrix in a manner similar to that of fillers used in composite materials even though PS and polyolefins are generally considered to be incompatible [Nosker et al., 1990].

An example of static bending deflection loading of various plastic wood products manufactured by Polymerix is shown in Figure 2.1. This company's products are upgraded from standard extruded plastic lumber with glass fiber reinforcing and a foamed core. It provides deflection load properties similar to the southern yellow pine (Figure 2.1) which is the company's primary wood competitor. The tests were run on a standard 2x4 piece of lumber. Unreinforced, unfoamed plastic lumber has deflection load properties that are less than that of southern yellow pine (Figure 2.1).

Table 2.3 Changes in Mechanical Properties of Plastic Tailings with Addition of Polystyrene [Nosker et al., 1990]

Composition (%)		Compressive Modulus (psi)	Yield Stress (psi)	Compressive Strength (psi)
0 PS	100 tailings	90,000	2,700	3,170
10 PS	90 tailings	144,370	3,100	3,,220
20 PS	80 tailings	163,390	3,860	3,860
30 PS	70 tailings	197,600	4,350	4,350
35 PS	65 tailings	239,000	4,950	4,950
40 PS	60 tailings	222,300	4,750	4,750
50 PS	50 tailings	220,000	5,320	5,320
Standard Virgin Resins: [a]				
HDPE		90,000-150,000	-	2,500
LDPE		20,000-27,000	-	900-2,500
PP		100,000-170,000	-	4,000
PS		450,000	-	6,000-7,300

a. From Perry's Chemical Engineers Handbook, Sixth Ed. Modulus in tension shown.

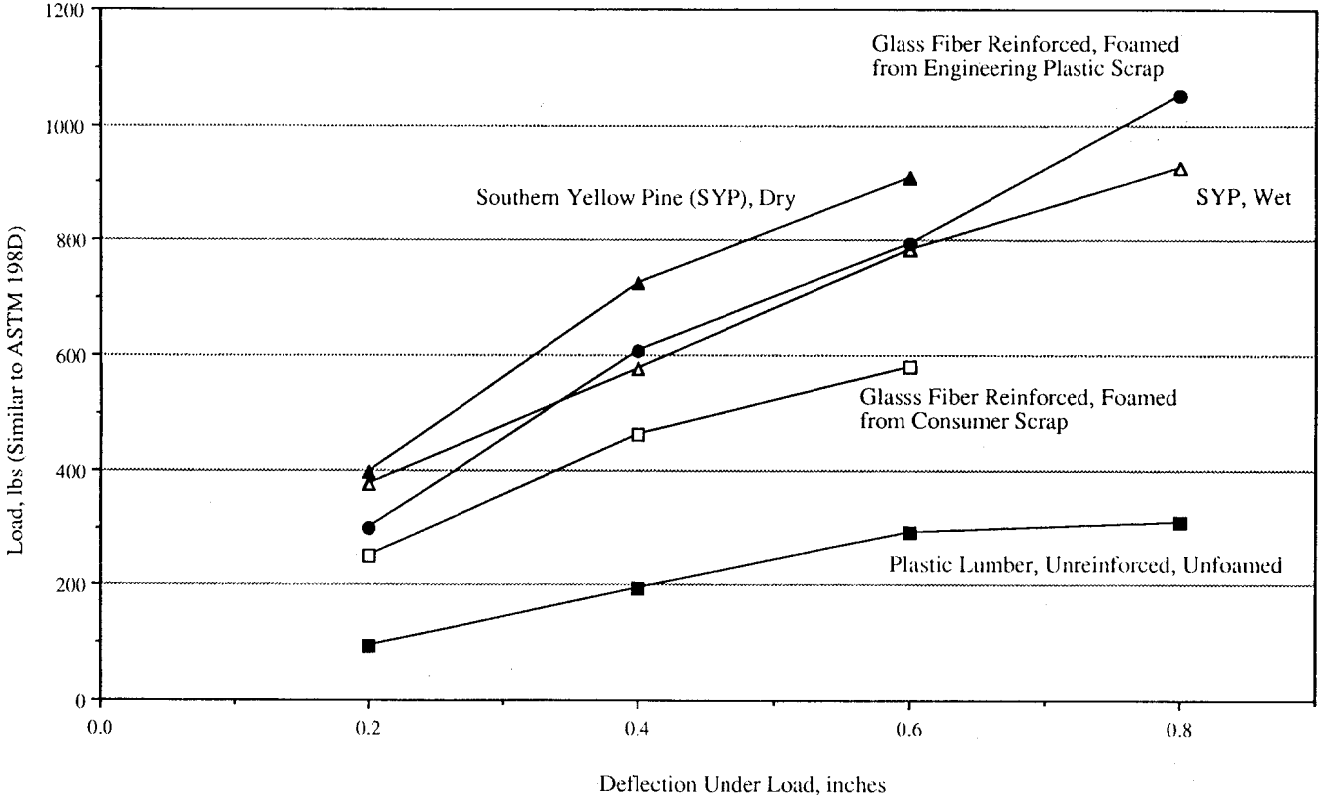

Figure 2.1 Static Bending Test Results of 2x4 Lumber Pieces [Mack, 1990]

2.6 Wood Fiber - Resin Composite Lumber

Wood fiber - recycled plastic composite lumber is a relatively new development and is similar to PS addition to plastic lumber because the potential exists for improved mechanical properties and dimensional stabilities. Wood fiber addition can serve as an excellent reinforcement for plastics, and wood fibers are abundant, lightweight, nonabrasive, nonhazardous and inexpensive. An effort is being made to examine the incorporation of treated and untreated aspen fibers into recycled HDPE milk bottles [Yam et al., 1990]. The work has shown tensile strength and Izod impact strength below that of HDPE alone when aspen fiber is added. Tensile modulus and flexural modulus are increased significantly above HDPE alone with the addition of wood fiber. Dispersion of the fiber in the resin has been reported as a dominating factor in the process thus far.

Another effort is being made to examine the recycle of wood fiber-PS composites into the same material and testing the resultant product under extreme conditions (e.g., exposure to boiling water, at room temperature, 105°C and -20°C). The composite material was reground to a number 20 mesh size and remolded three times in the experiment. Compared with the original extruded composite, the mechanical properties and dimensional stabilities of the recycled material did not change significantly even after exposure under extreme conditions. Detailed data on the study are contained in Maldas and Kokta [1990].

2.7 Future of Mixed Plastic Lumber

Whether mixed plastic lumber survives as part of the long term solution to post consumer waste plastic is unclear. There are currently a number of hurdles with such a product. It is uneconomical to ship relatively low density low-value waste plastic more than 100-200 miles for production. There are clearly technical advantages of plastic wood in certain applications, and therefore its manufacturing cost must be compared to similar outdoor grade wood products. An effective infrastructure for collection, transport, processing and marketing of plastic lumber product is necessary in the area where waste plastic is generated in order for plastic lumber to be a long term viable alternative. For Illinois, the best location for such a facility would be the metropolitan Chicago area. A metropolitan area can provide consistent volumes of feed material to support an operation 24 hours a day, 7 days per week and allow for the removal of high grade, high priced waste plastics from the waste stream while processing the "tailings" and providing markets for products.