CHELSEA CENTER FOR RECYCLING AND ECONOMIC DEVELOPMENT
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Accelerated Aging of Specific Formulations of Recycled High Density Polyethylene Based Landscape Timbers

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The Chelsea Center for Recycling and Economic Development, a part of the University of Massachusetts' Center for Environmentally Appropriate Materials, was created by the Commonwealth of Massachusetts in 1995 to create jobs, support recycling efforts, and help the economy and the environment by increasing the use of recyclables by manufacturers. The mission of the Chelsea Center is to develop an infrastructure for a sustainable materials economy in Massachusetts, where businesses will thrive that rely on locally discarded goods as their feedstock and that minimize pressure on the environment by reducing waste, pollution, dependence on virgin materials, and dependence on disposal facilities. Further information can be obtained by writing the Chelsea Center for Recycling and Economic Development, 180 Second Street, Chelsea, MA 02150.

TABLE OF CONTENTS

1. SCOPE OF THE STUDY

The purpose of this study was to evaluate the mechanical performance of a specific recycled plastic material formulation used for the production of injection molded landscape timbers. Landscape timbers of this type are utilized in a number of outdoor applications, such as in the construction of retaining walls. The extended service life for products of this type has raised concerns as to the effects of long term exposure to the weather. The specific material formulation evaluated was based primarily on recycled high density polyethylene (HDPE), and as such, will exhibit excellent resistance to the long term effects of moisture. However, the long term effect of sunlight exposure in the presence of oxygen is one of the primary causes of concern for plastic products slated for long term, outdoor applications. Other potential problems associated with the application such as creep deformation, flammability, thermal deformation, low temperature brittleness, and flame retardance were not considered in this study.

It was thought that the potential problems associated with long term sunlight exposure could be a concern for this particular landscape timber product for two reasons. One of these reasons is associated with the relatively thin wall nature of the injection molded timber. This specific injection molded (largely open) landscape timber has a partially foamed, nominal wall thickness in the 8 mm range, unlike solid or foamed plastic landscape timbers that have wall thickness equivalent to the total thickness of the board itself. Since sunlight exposure is a essentially a surface related problem for pigmented plastics, it's effect on product performance is in part related to product geometry or thickness. Thin plastic films or coatings represent one geometric extreme where aging is most significant, while very thick, conventional plastic lumber represents the other extreme. The effect of light exposure on the mechanical performance of this relatively thin wall, injection molded lumber is investigated in this study.

A second concern for this product (like most plastic lumber products) is that the material formulation used in manufacturing is based upon recycled, rather than virgin feedstock. In the case of virgin plastic products, the material formulation (i.e. the plastic and its additive package) are specifically selected for the end used application. In the case of recycled products, the material formulations utilized are based upon both the end use requirements and recycle material availability. The specific plastic materials utilized for this landscape product were originally selected for other, perhaps less demanding applications. Their performance in this long term application is uncertain.

In this study, the effects of light exposure on the performance of the HDPE based lumber formulation have been evaluated. The mechanical performance of the landscape timber material formulation (including a brown pigment) has been evaluated as molded (for control purposes) and after approximately eight (8) years of simulated sunlight exposure in a carbon arc test apparatus. In addition, several other HDPE formulations (using the same base resin) were prepared in order to evaluate the effect of ultraviolet light stabilizing additives.

2. EXPERIMENTAL

The following experimental section outlines the materials, compounding procedures, molding procedures, and testing procedures utilized for the study.

Materials: The recycled HDPE materials and the pigment concentrate used in this study were supplied by SelecTech, Inc., Taunton, MA. Two types of clean, post industrial recycled HDPE (one high melt flow rate injection molding grade, one fractional melt flow rate grade) were dry blended using a V-shell blender in equal parts (50%/50%) as the "base resin" for this study. This HDPE blend was then dry blended with chocolate brown color concentrate (LDPE carrier) at a 2.5% concentration (40:1 let down ratio). The color concentrate was also supplied by SelecTech, Inc. While a small amount of foaming agent is normally used in the timber production formulation to minimize sink problems, it was not incorporated during this study in order to minimize the likelihood of internal void formation in the test samples (causing a number of test result errors). The formulation described above was used as the control formulation for the study.

Additional formulations were prepared using ultraviolet light stabilizers. The specific stabilizers utilized were (i) Tinuvin® 791 (a blend of oligomeric hindered amine stabilizers) manufactured by Ciba Specialty Chemicals, Tarrytown, NY, and (ii) Tinuvin® 328 (a hydroxyphenylbenzotriazole) also supplied by Ciba. The 791 has been shown to be an effective stabilizer for the polyolefins (especially polypropylene which is typically less stable than HDPE). The 328 is sometimes used in combination with the 791 for additional protection. Each of these additives was in powder form and was used in concentrations that range from typical to above average.

The following specific formulations were dry blended prior to melt compounding:

Formulation 1.	HDPE Blend / Pigment (control and current formulation)
Formulation 2.	HDPE Blend / Pigment + 0.2% 791
Formulation 3.	HDPE Blend / Pigment + 0.5% 791
Formulation 4.	HDPE Blend / Pigment + 1.0% 791
Formulation 5.	HDPE Blend / Pigment + 0.5% 791 + 0.2% 328
Formulation 6.	HDPE Blend / Pigment + 0.5% 791 + 0.4% 328

Total formulation batch weight was 10 lbs in each case.

Sample Preparation: The dry blended formulations (1-6) were then melt blended using a 30 mm Werner Pfleiderer ZSK co-rotating intermeshing twin screw extruder with a medium shear profile. The degree of melt mixing (both distributive and dispersive) is typically very good when compounding equipment of this type is utilized. Barrel set temperatures ranged from 180°C (feed zone) to 210°C (die). The rod-like extrudate from the twin screw process was cooled and pelletized. Each formulation, including the control, were processed in the same manner.

After melt compounding, the compounded pellets were then injection molded into ASTM test specimens (including ASTM Type IV tensile bars). The sample thicknesses were 3.2 mm. Injection molding was done on a Cincinnati Milacron MC 22 Ton injection molding machine, equipped with the ASTM test specimen mold. The molding barrel temperatures were held at 190°C, while the mold temperature was held at 50°C. Processing conditions were held constant for each formulation. Once the process had stabilized, a total of thirty sets of test samples were prepared for each formulation.

Sample Exposure: After molding, approximately 1/3 of the samples for each formulation were loaded into holding frames, and placed in a Carbon Arc Accelerated Light Exposure Chamber (ASTM G 23 Type D with a Pyrex filter) for approximately 65 days (semi-continuous with several interruptions). Samples were rotated on a regular basis. While it is extremely difficult to obtain an exact correlation between this accelerated test and real life sunlight exposure conditions, this number of hours in the accelerated test chamber represents a number of years of sunlight exposure (on the order of 7-8 years of warm climate outdoor use). While the service life of this product is expected to be significantly longer than this time period, property deterioration due to aging is a gradual (rather than sudden) change. The chamber temperature during testing was at or near 130°F for the duration of the test. The samples held in the holding frames were exposed to the carbon arc on one side only, as this would be the case for the landscape timber itself.

Property Evaluation: The mechanical properties of the unexposed and exposed sample sets were evaluated in an effort to determine (i) the effect of simulated sunlight aging, and (ii) to determine the effectiveness of the ultraviolet stabilizing additives. The mechanical properties evaluated were tensile properties in accordance with the ASTM D638 test protocol. An extension rate of 10 inches/minute was used for all tensile testing. The number of replicate samples that could be tested was limited by the capacity of the carbon arc chamber itself which was loaded to its maximum capacity. A total of eight (8) replicate samples were tested for each particular formulation (8 exposed - 8 unexposed in each case).

It is somewhat more common to test aged samples in bending (rather than tension) since the aged surface of the sample can be tested in such a way that it is exposed to an outer fiber tensile stress during bending. However, the very flexible nature of these HDPE samples (even the aged samples) would not result in failure using this testing method. While tensile tests do not magnify the effect of surface aging, they do provide an ultimate elongation or failure strain values that could not be obtained via bending. The tensile testing procedure was used for this reason. For design purposes, one can assume that the tensile and flexural modulus values obtained from these test would be very similar.

3. DISCUSSION AND RESULTS

In general, the results of this aging study were very positive with respect to the long term simulated sunlight aging performance of the HDPE landscape timber formulations. The average tensile test results are summarized in Table 1. All of the formulations, including the unmodified control formulation, showed very very little change in tensile properties after the long term exposure to the carbon arc, which again simulates 7-8 years of outdoor exposure. The control formulation showed no significant changes in tensile modulus, tensile yield strength or tensile yield elongation. (Note that the tensile modulus numbers reported in Table 1 are low due to the fact that strains were based on jaw separation rather than extensometer measurements). There was a reduction ultimate tensile elongation from 121% to 100%, however, this change may or may not be significant. Tensile elongation is in fact the most sensitive property to aging (ultimate elongation will usually decrease with age), however, it is also the property that is most sensitive to sample quality (voids, contamination etc). It is very common for the ultimate elongation of “recycled” plastics to vary significantly from batch to batch or sample to sample due to the likelihood of contamination with recycled plastics. This is confirmed by the relatively high standard deviations for all ultimate elongation values. This reduction in ultimate elongation for the control formulation could be significant, however, the difference is within the range of error commonly observed when testing the ultimate elongation of recycled plastics.

The mechanical property retention after aging is confirmed by the fact that the sample did not show any significant degree of color change or significant surface quality deterioration. Color retention was very good. There was some evidence of crazing on the surfaces of the samples exposed to the carbon arc (crazes appear as very small surface scratch like features). These minor surface imperfections may possibly account for the small reduction in the ultimate elongation value.

In general, the tensile property test results for formulations #2-#6 were not significantly different than those of the unmodified control sample (overall). These additives are used in very low concentration, and as such did not have any significant effect on the unaged properties. These additives would "normally" be expected to result in better property retention for the simulated sunlight aged samples. However, since in this case, the aged samples had very good property retention, it is essentially impossible to draw conclusions regarding the effect of these additives. Looking again at the ultimate elongation values, there is no clear cut trend regarding ultimate elongation retention for the formulations containing the additives. In three cases (#2,4,5), the ultimate elongation values decreased after aging while in two cases (#3,6), the ultimate elongation values increased. Most likely, these changes (±) were associated with factors such as test error or material variations rather than the aging. There is no specific or significant trend as to the effect of these additives on tensile properties.

It is very likely that the lack of observed "degradation" (due to factors such as UV initiated oxidation...) is due in large part to the use of the dark brown pigment added to the base HDPE formulation. The opaque pigment limits the degree of light penetration and therefore the depth of the potential damage zone. More significant results would most likely have been obtained with thin film (pressed out) samples, rather than with the relatively thick 3.2 mm samples tested, due to the ratio of surface layer to overall thickness. The thicker samples were used for testing to obtain results that are more representative of the actual end product (which is actually even thicker than the test samples evaluated). It would be difficult or impossible to draw conclusions as to how the photo initiated degradation of a thin film sample would correlate with the performance of a thick walled product.

In retrospect, based upon the results of this study (or lack of significant property changes), it would have been better to test both thick wall and thin film samples. The the thin film sample should be more appropriate for the additive study, while the thicker sample would provide results that are more representative of actual product performance.

4. CONCLUSIONS

The results of this accelerated aging study on the HDPE based landscape timber materials show that all of the formulations evaluated exhibit very good tensile property retention after several months of carbon arc testing. This period of time in the carbon arc chamber correlates with approximately eight years of outdoor exposure. The changes in tensile properties associated with this time of exposure were not significant, even for the unmodified control samples. The stabilizing additives did not have any negative effect on either the exposed or unexposed samples. No conclusions regarding the positive effects of these additives could be drawn since no significant exposure related tensile property deterioration occurred for the unmodified (control formulation) samples. Prior art suggests that these additives should be effective in providing additional ultraviolet light stability for polyolefins. Their use in no way appears to be detrimental, and therefore a UV stabilizer could be used for additional confidence. The primary problems associated with their use would likely be economic.

TABLE 1
TENSILE TEST RESULTS BEFORE AND AFTER EXPOSURE TO CARBON ARC

Formulation (see page 2)	**Initial Modulus (MPa)**	**Yield Stress (MPa)**	**Yield Elongation (%)**	**Ultimate Elongation (%)**
1 Unaged	387 (8.02)	26.2 (0.14)	17.8 (0.85)	121 (7.18)
1 Aged	373 (43.6)	27.1 (0.49)	19.2 (0.64)	99.9 (5.12)
2 Unaged	371 (42.0)	26.1 (0.27)	17.9 (1.74)	127 (28.0)
2 Aged	417 (8.20)	28.6 (0.29)	19.3 (0.77)	80.1 (1.64)
3 Unaged	392 (11.9)	25.7 (0.36)	18.6 (1.03)	99.8 (6.90)
3 Aged	398 (11.6)	27.1 (0.26)	19.7 (1.67)	105 (3.85)
4 Unaged	360 (14.3)	25.6 (0.17)	20.28 (1.48)	126 (24.1)
4 Aged	392 (4.43)	27.2 (0.40)	21.48 (1.30)	90.6 (5.21)
5 Unaged	395 (11.2)	25.8 (0.30)	19.2 (1.21)	90.2 (6.90)
5 Aged	403 (10.7)	27.3 (0.39)	20.2 (1.49)	80.2 (10.4)
6 Unaged	366 (26.9)	28.0 (0.35)	18.4 (2.10)	80.0 (8.10)
6 Aged	407 (16.3)	27.8 (0.78)	21.0 (1.52)	120 (15.9)

* Values in ( ) are the standard deviation.