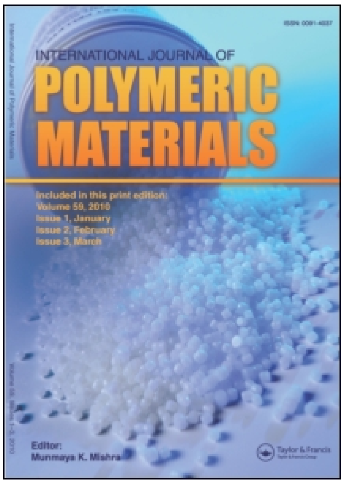

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Structural properties of recycled hdpeplastic lumber decking planks

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STRUCTURAL PROPERTIES OF RECYCLED HDPE PLASTIC LUMBER DECKING PLANKS

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Plastic lumber is being used to replace wooden lumber in some construction applications, especially in outdoor applications where the plastic lumber is presumed to weather better than the wood. However, the structural properties of the plastic lumber are not well understood, and the use of plastic lumber in structural applications is not authorized in the common building codes. Contractors who use plastic lumber in structural applications such as outdoor decks are in most cases violating the building codes. In this research effort, standard 1×6 tongue-in-grove plastic lumber planks were tested for many different structural properties. The tests were conducted at $-23.3°C$ to simulate winter conditions, and at $40.6°C$ to simulate summer conditions. In all cases the high temperature strength and stiffness was lower than at low temperature, so the high temperature values would determine the allowable strength and stiffness for design. The conclusion was that the plastic lumber is a good structural material, but that it is not appropriate to simply substitute plastic lumber for wooden lumber pieces of the same size in structural applications. The plastic lumber is not as strong and stiff as the wooden lumber, and so larger sizes must be used to obtain the same strength and stiffness. Because of the much lower modulus, compression members made from plastic lumber may need to be of much larger size to resist buckling.

Keywords: plastic lumber, strength, modulus, fastener strength, sustained load, slip resistance

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1. INTRODUCTION

Wooden lumber is an excellent construction material, and is used in many construction applications. Unfortunately we are reaching a point in time when the earth cannot produce enough lumber to meet our building needs. There are many companies making products which can replace lumber in construction applications. Steel, plastic, and plastic composites are the most common materials used for the lumber substitutes. The advantage of using steel is that it has been used in structural applications for many years, and its properties are well understood. The disadvantage of using steel is that it requires different tooling to cut and shape it, different fasteners to hold it together, and more safety precautions due to the sharp edges.

Plastic and plastic composites have been used more recently for lumber substitutes, and the structural properties of these materials are not as well understood. The advantage of using plastic lumber is that it can be cut and drilled with the same tools that would be used on wood, and can be fastened with the same nails and screws. Plastic lumber has more consistent properties from board to board than does wooden lumber, is less likely to split or splinter, is rot resistant and does not contain hazardous chemicals like CCA (chromated copper arsenate) or creosol treated lumber.

The primary disadvantage of plastic lumber is that it has not been adequately tested and does not meet the common building code requirements. Contractors who use plastic lumber in structural applications are in most cases violating the building codes. There are many companies making plastic lumber with varying material properties. There are no universal standards for plastic lumber, and even if such standards were developed, most companies do not have adequate quality control programs to insure that their products meet minimum standards [1]. Some plastics soften with increasing temperature, and there is concern that the plastic lumber may not have adequate structural strength on a hot summer day. Some plastics become brittle with decreasing temperature, leading to concern that the plastic lumber may experience a brittle failure in the winter. Plastics are susceptible to UV radiation, and so the plastic lumber must have UV inhibitors to protect it if exposed to the sun. The plastic lumber must be fire retardant, and there may be additional application specific concerns.

Plastic lumber products are currently more expensive than CCA treated lumber. However, these products are in the early part of their development cycle. It is likely that plastic lumber products will steadily improve in quality and become less expensive. At some point they will become less expensive than wood, and will be preferred to wood as a building material. This will ease the cutting demands on our forests to provide lumber for construction. The inherent rot, marine, and termite resistance of plastic lumber will reduce the leaching of hazardous chemicals into the environment, like CCA and creosol treated lumber [2].

Post consumer plastic waste is used in many of the plastic lumber products, so the plastic lumber will reduce the amount of material that must be land filled. There are billions of kilograms of plastic land filled each year in the USA alone, and much of that plastic could be recycled into plastic lumber [3, 4]. Recycled plastic collection and sorting contributes the highest cost of using recycled plastic for plastic lumber [3, 4]. Plastic lumber has different mechanical properties than wooden lumber, and designs with plastic lumber should be different than with wooden lumber [3, 4]. New structural designs may need to be developed which take advantage of the properties of the plastic lumber [4, 5].

There have been several studies measuring the structural properties of various types of plastic lumber products [6–16]. Weathering in a marine environment for two years was shown to have only minor effects on the strength and modulus of the plastic lumber [6]. The strength of plastic lumber is comparable to that of wooden lumber, but the modulus is much lower [1–9]. Different types of reinforcement have been used to improve the modulus of the plastic lumber [10–12]. Fatigue properties of the plastic lumber are difficult to measure because the lumber heats up during the fatigue test, and plastic properties are sensitive to temperature [13]. The creep behavior of HDPE plastic lumber is very similar to the creep behavior of virgin HDPE material [14–15]. The strength of bolted and nailed connections in plastic lumber decreases as the temperature is raised [16]. In this paper we report the material properties of HDPE recycled plastic lumber. A battery of ASTM tests for wooden lumber were modified for the plastic lumber. The results represent a significant addition to understanding of the structural properties of HDPE plastic lumber.

2. EXPERIMENTAL

The goals of this research project were to better understand the structural properties of Polyex® plastic lumber product. Polyex® is made from recycled plastic milk jugs, and so the material is pure HDPE with pigment for color and some other proprietary additives. Tests were performed at a low temperature to simulate winter conditions and a higher temperature to simulate summer. Twelve different

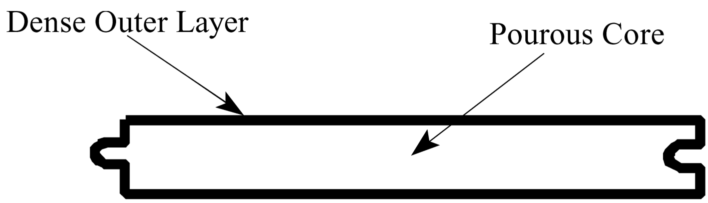

FIGURE 1 Plastic lumber cross-section.

structural properties were measured to determine how this material would perform as a structural material. Standard 1×6 tongue-in-grove plastic lumber boards commonly used in building outdoor decks and porches were used for all of the testing. These boards are nominally 1.9 cm (0.75 inch) thick and 15.24 cm (6 inch) wide.

Plastic lumber is a porous material. The manufacturers deliberately incorporate some porosity. If the boards were solid plastic, then driving a nail or screw into them would likely crack or split the material. The porosity allows the plastic lumber to better accommodate fasteners. The outer shell of the lumber was solid, and the interior core was porous, as illustrated in Figure 1. Since the porous core will have different properties than the outer shell, the lumber must be tested in its full thickness configuration. It would not be appropriate to machine small specimens out of the core material because the properties of those samples would not be characteristic of the plastic lumber. All tests for this research work were conducted on samples that were the full thickness of the 1×6 tongue-in-grove lumber. Four different colors of the plastic lumber were ordered so that it would be certain that material from at least four different production lots were obtained, and typical lot-to-lot variations could be observed.

2.1. Density

The design engineer needs to know the density of the material in order to calculate the dead load of the structure. The plastic lumber tested has a higher density than wood, and so the dead load will be higher than for wooden deck boards of the same shape. Density of the plastic lumber was tested in accordance with ASTM D792. This test uses the Archimedes principle to calculate density, and the plastic lumber was less dense than water, so weights had to be used to submerge the lumber and make the density measurements. A total of 24 specimens were tested, with six samples from the four different lots of material. The highest density measured was 0.86 g/cc, the lowest was 0.64 g/cc, and the average was 0.072 g/cc. The data showed that variations in density occurred by lot, and so the variation of 0.64 g/cc to 0.86 g/cc would be typical of lot to lot variation. Wooden lumber has a density of 0.5 to 1.0 g/cc; CCA and creosol treated lumber has higher density than untreated lumber. The conclusion is that the Polyex® lumber will cause approximately the same dead load on the structure as does wooden lumber. The 1×6 tongue-in-grove planks had a weight of 9.67 kg per meter (1.34 pounds per foot) length on the average.

2.2. Compressive Strength and Modulus

The plastic lumber was cut into specimens which were the nominal width and thickness of the lumber and 3.81 cm (1.5 inches) long. Specimen ends were milled to be sure they were square and parallel. An LVDT was used to measure the change in length of the specimens during the tests. Compression tests were conducted in accordance with ASTM D695. Eight tests were performed at -23.3°C (-10 F) and eight at 40.6°C (105 F) to simulate winter and summer conditions. Of the eight specimens tested at each temperature, two from each of four lots were included so that the lot to lot variation could be measured. The average compression strength and modulus at -23.2°C was 51.8 MPa (7.52 ksi) and 1.70 GPa (251 ksi) respectively. At 40.6°C the average values were 11.4 MPa (1.65 ksi) and 0.27 GPa (39.2 ksi) respectively. Figure 2 illustrates the lot to lot differences in compressive strength and modulus and how these values varied with temperature.

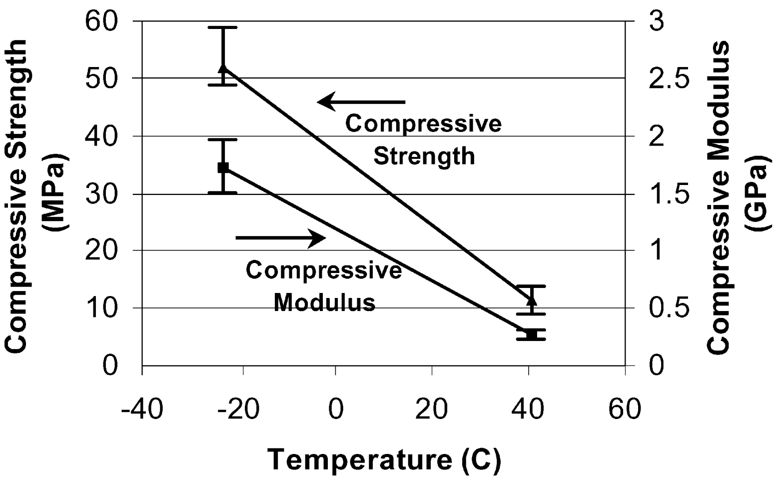

FIGURE 2 Compressive strength and modulus.

Wooden (fir) lumber has a compression strength parallel to the grain of 19 to 27 MPa and a flexure modulus of 8 to 11 GPa [17]. The compression strength of the Polyex® at 40.6°C (105 F) is approximately half that of wooden lumber. The compression modulus is lower by a factor of approximately 35! Compression modulus for different species of lumber are not commonly tabulated, so this comparison is between a compression modulus and a flexure modulus, but the data show a tremendous difference between the stiffness of wooden and Polyex® lumber. This does not mean that the plastic lumber is unsuitable for structural applications, but it does mean that larger cross-sections will have to be used to carry the same load. The extremely low modulus of the plastic lumber will have a large impact on the buckling capacity of plastic lumber columns. Very large cross-sections may be required for plastic lumber columns to prevent buckling.

2.3. Flexure Strength and Modulus

Specimens were cut 40.6 cm (16 inches) long at the nominal width and thickness of the lumber. The manufacturer had proposed to place the deck boards over joists which had a center-to-center spacing of 30.5 cm (12 inch), so the flexure tests were performed on a 30.5 cm major span and a 10.2 cm (4 inch) minor span. The tests were conducted in accordance with ASTM D790. Because of the porous nature of the plastic lumber the flexure modulus measured should be regarded as an "apparent" or "equivalent" modulus rather than a true modulus for the material. Twelve tests were performed at −23.3°C (−10 F) and twelve at 40.6°C (105 F) to simulate winter and summer conditions. Of the twelve specimens tested at each temperature, three from each of the four lots were included so that the lot to lot variation could be measured. The average flexure strength and modulus at −23.2°C was 36.6 MPa (5.31 ksi) and 2.21 GPa (327 ksi) respectively. At 40.6°C the average values were 8.84 MPa (1.28 ksi) and 0.50 GPa (39.2 ksi) respectively. Figure 3 illustrates the lot to lot differences in flexure strength and modulus and how these values varied with temperature.

The flexure modulus for this material is higher than either the compression modulus or tensile modulus, which is unusual. For most materials the flexure modulus is less than or equal to the tensile and compression modulus. The reason for this is that the dense outer layer of this plastic lumber has a higher modulus than the porous core material. The flexure test for measuring modulus gives more weight to the material near the top and bottom surfaces and less weight to the core material. The tensile and compression tests give equal weight to both materials. So because of the way the plastic lumber is

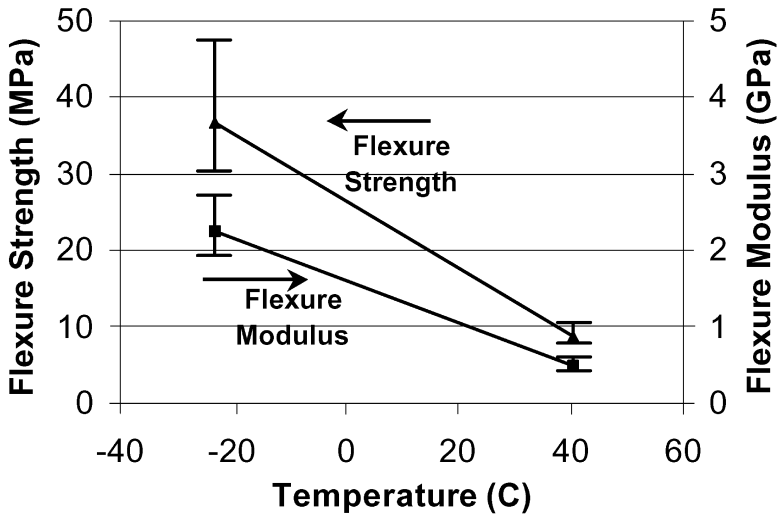

FIGURE 3 Flexure strength and modulus.

manufactured, it has a higher "apparent" modulus in flexure than in tension or compression.

Wooden lumber has a flexure strength of 40 to 53 MPa and modulus of 8 to 11 GPa. The flexure strength of the Polyex® at 40.6°C (105 F) is approximately 1/5th that of wooden lumber, and the flexure modulus is lower by a factor of approximately 20. Larger cross-sections or shorter spans will be required for the plastic lumber to carry the same load as the wooden lumber. The manufacturer for the Polyex® lumber recommends that the decking boards be supported on joists spaced at 30.5 cm (12 inch), whereas the same size wooden lumber would be placed on joists spaced at 40.6 cm (16 inch). The extremely low modulus of the plastic lumber will cause the boards to sag significantly more between the joists than does wooden lumber, and that may be unacceptable for some applications.

2.4. Tensile Strength and Modulus

Dog-boned shaped specimens were used for the tension tests. The gauge section was machined to precisely 2.29 cm (0.9 inch) wide and the nominal thickness of the lumber. The machined gauge length was 12.7 cm (5 inch) long and the overall length of the specimens were 25.4 cm (10 inch). Tests were conducted in accordance with ASTM D638. Eight tests were performed at −23.3°C (−10 F) and eight at 40.6°C (105 F) to simulate winter and summer conditions. Of the eight

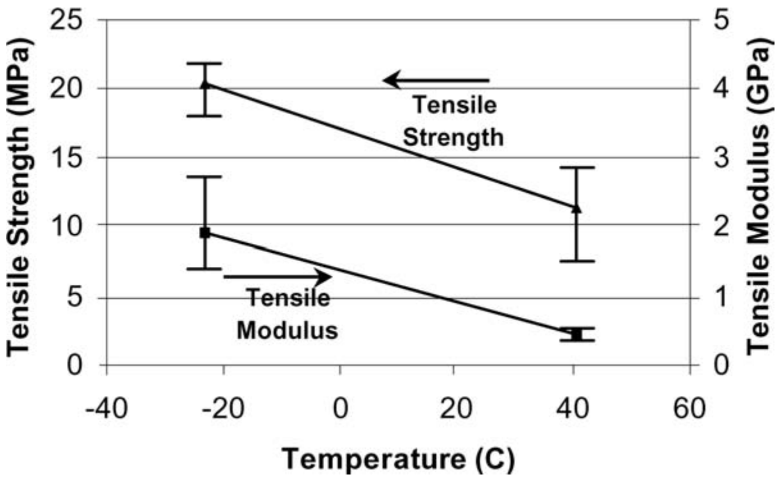

FIGURE 4 Tensile strength and modulus.

specimens tested at each temperature, two from each of four lots were included so that the lot to lot variation could be measured. The average tensile strength and modulus at −23.2°C was 20.3 MPa (2.95 ksi) and 1.89 GPa (251 ksi) respectively. At 40.6°C the average values were 11.5 MPa (1.66 ksi) and 0.44 GPa (64.1 ksi) respectively. Figure 4 illustrates the lot to lot differences in tensile strength and modulus and how these values varied with temperature.

Tensile strength and modulus are not commonly measured for wooden lumber; it is common to use the flexure strength and modulus of 40 to 53 MPa and 8 to 11 GPa respectively for design purposes [17]. The tensile strength of the Polyex® at 40.6°C (105 F) is approximately 1/4th that of wooden lumber, and the flexure modulus is lower by a factor of approximately 20. Larger cross-sections will be required for the plastic lumber to carry the same tensile load as the wooden lumber. The extremely low modulus of the plastic lumber will cause the boards to elongate significantly under load, which could make it an unacceptable material choice, but the low stiffness would not be a problem in most tension applications.

2.5. Shear Strength

Punch tests in accordance with ASTM D732 were conducted to measure the shear strength of the plastic lumber. For the test, a 2.54 cm (1 inch) diameter steel cylinder was pressed through the lumber, punching out a 2.54 cm diameter puck. Shear strength calculations

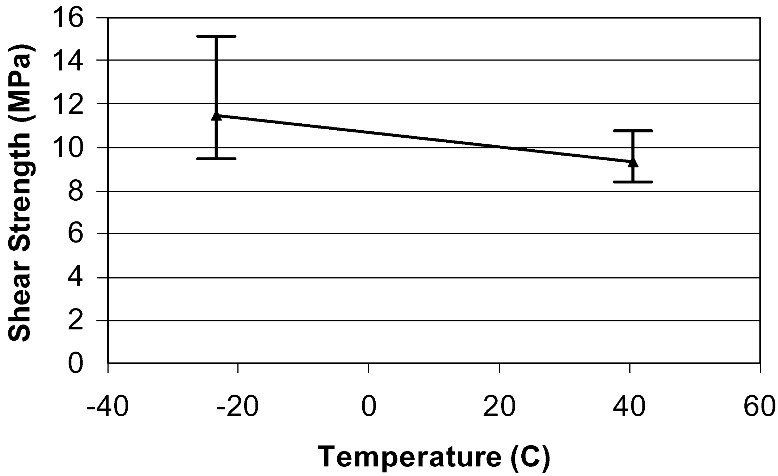

FIGURE 5 Shear strength.

were made from the test results, but there was no attempt to measure the shear modulus. Eight tests were performed at −23.3°C (−10 F) and eight at 40.6°C (105 F) to simulate winter and summer conditions. Of the eight specimens tested at each temperature, two from each of the four lots were included so that the lot to lot variation could be measured. The average shear strength at −23.2°C was 11.4 MPa (1.66 ksi). At 40.6°C the average value was 9.35 MPa (1.35 ksi). Figure 5 illustrates the lot to lot differences in shear strength and how these values varied with temperature.

Wooden lumber has a shear strength of 5 to 7 MPa. The shear strength of the Polyex® at 40.6°C (105 F) is greater than that of wooden lumber, and so it was concluded that there is an improvement in shear strength when using the plastic lumber. Shear strength is very important in holding the nails and screws and making secure structural connections. The results of the shear strength tests are a good indication that the connections in plastic lumber structures will be as strong or stronger than similar connections in wooden lumber structures. This conclusion is further supported by the pull-out and lateral load tests conducted on nails and screws below.

2.6. Sustained Load at Elevated Temperature

Specimens were cut at the nominal width and thickness of the lumber and 40.6 cm (16 inches) long. The sustained load tests were performed on a 30.5 cm (12 inch) major span and a 10.2 cm (4 inch) minor span.

The tests were conducted in accordance with ASTM 2164. A dial gauge was used to measure the deflection of the center of the beam over a 48 hour period. Specimens were loaded with 586 kg per square meter (120 pounds per square foot) using dead weights, and the change in deflection of the center of the span was measured. Eight tests were performed at 40.6°C (105 F) to simulate the creep that would occur during summer conditions. Of the eight specimens tested, two from each of four lots were included so that the lot to lot variation could be measured. The average deflection over a 48 hour period was 0.460 cm (0.181 inch). Figure 6 shows deflection *vs.* time for the eight boards tested. Two of the boards displayed significantly more creep than the other six. These two were both the same color and from the same production lot, so this is probably typical of a lot-to-lot variation in the creep.

The typical design load for decking material is 293 kg per square meter (60 pounds per square foot), so the creep test was performed at twice the typical design load. The average deflection was 1/66th of the span, which is a noticeable deflection. The plastic lumber planks would probably exhibit a noticeable permanent sag between the joists if left loaded continuously during the summer. Dry wooden lumber would not creep significantly under this load, but with moisture (rain) and a constant applied load the planks would gradually warp into a shape similar to the plastic lumber planks. More testing is required to determine if the creep exhibited by the plastic lumber is acceptable, but it appears from these tests that the creep in the plastic lumber is similar in magnitude to the warping of wooden lumber.

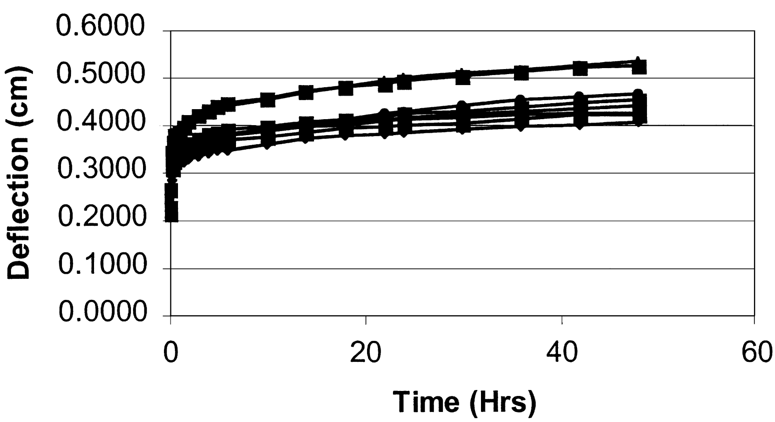

FIGURE 6 Sustained load results.

2.7. Screw and Nail Withdrawal

Tests were conducted to measure the pull-out load for #8 screws with no pilot hole, #10 screws with a 3.18 mm (1/8 inch) pilot hole, 6.35 mm (1/4 inch) lag screws with a 4.76 mm (3/16 inch) pilot hole, 8 penny galvanized nails with no pilot hole, and 6 penny galvanized nails with no pilot hole. The specimens were nominally 40.6 cm (16 inch) long and the nominal width and thickness of the plastic lumber. Six fasteners were placed at 5 cm (2 inch) intervals along the length of the specimen. The fasteners were arranged so that each specimen had at least one of each of the five fasteners tested. This arrangement measures the pull-out strength of each fastener in each specimen, and yields a better overall average for the pull-out strength for each fastener. The fasteners were driven completely through the boards so that they extended 12.7 mm (1/2 inch) on the back side.

Pull-out test were conducted in accordance with ASTM D1761. The specification states that the tests are invalid if failure occurs by breaking or pulling the head off the fastener rather than pulling the fastener out of the lumber. Approximately 20% of the failures during the tests were due to failure of the fastener. This is reported to point out that the pull-out strength of the lumber is approximately equal to the strength of the fasteners. Only the results of the valid tests were used in calculating the average pull-out strengths of the fasteners. Tests were performed at -23.3°C (-10 F) and at 40.6°C (105 F) to simulate winter and summer conditions. There were between five and nine valid tests for each fastener at each temperature. Details of the test results are given in Table 1.

Pull-out loads for fasteners in wooden lumber have been studied, and the formula for estimating the pull-out load for a nail in dry lumber is given by [18]:

$$W = 0.971\ G^{2.5}DL \tag{1}$$

where W is the pull-out load in kg, G is the specific gravity of the wood, D is the nail diameter in mm and L is the length of penetration into the lumber in mm. Assuming a specific gravity of 0.6, the pull-out loads for 6 and 8 penny nails with 19 mm (0.75 inch) penetration are 14.8 kg and 17.2 kg respectively. Comparing these values with Table 1, the pull-out strength of the plastic lumber is significantly higher than for wooden lumber.

A similar formula was developed for pull-out loads of screws in dry wooden lumber [18]:

TABLE 1 Results of Fastener Pull-Out Tests

Fastener	Results at −23.3°C Average	High	Low	Results at 40.6°C Average	High	Low
#8 Screw	289 kg [636 lbs]	366 kg [806 lbs]	205 kg [451 lbs]	215 kg [472 lbs]	290 kg [639 lbs]	179 kg [394 lbs]
#10 Screw	297 kg [653 lbs]	340 kg [747 lbs]	243 kg [534 lbs]	211 kg [464 lbs]	273 kg [600 lbs]	164 kg [360 lbs]
6.35 mm lag [1/4 inch lag]	425 kg [936 lbs]	581 kg [1279 lbs]	323 kg [711 lbs]	273 kg [600 lbs]	314 kg [690 lbs]	222 kg [488 lbs]
8 penny nail	64.1 kg [141 lbs]	95.9 kg [211 lbs]	50.0 kg [110 lbs]	42.7 kg [93.9 lbs]	56.8 kg [125 lbs]	32.5 kg [71.4 lbs]
6 penny nail	45.3 kg [99.6 lbs]	55.5 kg [122 lbs]	30.9 kg [67.9 lbs]	32.1 kg [70.7 lbs]	43.9 kg [96.6 lbs]	23.5 kg [51.8 lbs]

$$W = 2.00\ G^2 DL \tag{2}$$

where W is the pull-out load in kg, G is the specific gravity of the dry lumber, D is the screw diameter in mm and L is the screw penetration length in mm. Assuming a specific gravity of 0.6, the pull-out loads for #8 and #10 screws with 19 mm (0.75 inch) penetration are 57.0 kg and 66.0 kg respectively. Comparing these values with Table 1, the pull-out strength of the plastic lumber is significantly higher than for wooden lumber.

The lateral resistance formula for lag screws is [18]:

$$W = 2.84\ G^{1.5} DL \tag{3}$$

where W is the pull-out load in kg, G is the specific gravity of the dry lumber, D is the lag screw diameter in mm and L is the penetration length in mm. Assuming a specific gravity of 0.6, the pull-out load for the 1/4 inch lag screw with 19 mm (0.75 inch) penetration is 159 kg. Once again this is significantly lower than the pull-out load listed for the plastic lumber. All of the tests indicate that the pull-out strength of common fasteners in the Polyex® plastic lumber is higher than would be expected for wooden lumber.

2.8. Lateral Strength for Screws and Nails

Tests were conducted to measure the lateral strength for #8 screws with no pilot hole, #10 screws with a 3.18 mm (1/8 inch) pilot hole, 6.35 mm (1/4 inch) lag screws with a 4.76 mm (3/16 inch) pilot hole, 8 penny galvanized nails with no pilot hole, and 6 penny galvanized nails with no pilot hole. The specimens were nominally 30.5 cm (12 inch) long, 7.62 cm (3 inch) wide and the nominal thickness of the plastic lumber. Specimens were overlapped and attached with one fastener. The fasteners were driven completely through the boards so that they extended 12.7 mm (1/2 inch) on the back side. A dial gauge was mounted to measure the relative displacements of the two specimens during the test. Lateral load and relative displacement of the specimens were taken for cross-head displacements of 0.254, 0.381, 1.27, 2.54, and 7.62 mm (0.01, 0.015, 0.05, 0.1, and 0.3 inches). Specimens were loaded to failure, and the maximum lateral load the connection could withstand was recorded. Five tests were performed for each fastener at each temperature. Each test had two specimens from the same lot of material fastened together. Each fastener was tested in each of the four lots of material available so that a good average lateral strength value could be obtained. Lateral strength tests were conducted in accordance with ASTM D1761. Tests were performed at −23.3°C (−10 F) and at 40.6°C (105 F) to simulate winter and summer conditions. The most interesting results for the lateral resistance tests are given in Table 2. The complete ASTM specified data set can be obtained by contacting the author.

The formulas for estimating lateral strength of fasteners in wooden lumber are more complex than for estimating pull-out loads. The procedure is straightforward and well documented [18] and will not be repeated here. The lateral resistance numbers calculated were 41.0 kg, 49.8 kg, 79.6 kg, 106.9 kg, and 117.5 kg for the 6 penny, 8 penny, #8 screw, #10 screw and 1/4 inch lag screw respectively.

TABLE 2 Results of Fastener Lateral Strength Tests

	Results at −23.3°C			Results at 40.6°C		
Fastener	Average	High	Low	Average	High	Low
#8 Screw	356 kg [784 lbs]	408 kg [900 lbs]	395 kg [871 lbs]	249 kg [550 lbs]	288 kg [636 lbs]	197 kg [434 lbs]
#10 Screw	461 kg [1016 lbs]	515 kg [1136 lbs]	303 kg [670 lbs]	190 kg [419 lbs]	224 kg [494 lbs]	155 kg [342 lbs]
6.35 mm lag [1/4 inch lag]	624 kg [1376 lbs]	749 kg [1652 lbs]	529 kg [1167 lbs]	352 kg [776 lbs]	409 kg [901 lbs]	224 kg [494 lbs]
8 penny nail	191 kg [422 lbs]	216 kg [476 lbs]	172 kg [380 lbs]	120 kg [264 lbs]	135 kg [298 lbs]	97 kg [214 lbs]
6 penny nail	156 kg [343 lbs]	192 kg [424 lbs]	127 kg [281 lbs]	100 kg [220 lbs]	125 kg [276 lbs]	91 kg [200 lbs]

Comparing these values with Table 2 it is clear that the plastic lumber can withstand higher lateral loads than the wooden lumber for all of the fasteners tested.

2.9. Slip Resistance

Testing for slip resistance of the plastic lumber was conducted in accordance with ASTM D2394. Slip resistance tests were conducted since the intended use of the plastic lumber is as decking and surface slickness impacts user safety. The specification calls for measuring the coefficient of static friction and the coefficient of sliding friction between the plastic lumber and a standard grade of shoe leather. The tests were performed at room temperature. The average coefficient of static friction was 0.35, and the average coefficient of sliding friction was 0.20. The building codes do not give a minimum allowable specification for coefficient of friction, so the designer must decide if these coefficients of friction are acceptable and safe for the public.

The Polyex® plastic lumber is more slippery than wooden lumber, which has a coefficient of static friction of approximately 0.5 and a coefficient of sliding friction of 0.4 with shoe leather [19]. Though not a scientific test, plastic lumber planks were laid on the floor and people walked on them with different types of shoes. The plastic lumber seemed more slippery than wooden lumber for any type shoe. Adding water made the plastic lumber slick to the point that it was probably unsafe. Wooden lumber is sometimes coated with a thick polymer to protect it, and the coating may be just as slippery as the plastic lumber, but such coatings are seldom used in outdoor applications where they would get rained on. It is the opinion of the authors that this Polyex® plastic lumber needs a slip resistant coating or some modification of the surface finish to be safe for outdoor decking material.

3. SUMMARY AND CONCLUSIONS

Many structural properties of Polyex® plastic lumber, made from recycled HDPE milk jugs were measured. Tests were performed at a low temperature to simulate winter conditions and at a high temperature to simulate summer conditions. In all cases the strength and stiffness were lower at the high temperature, and so design strength and stiffness for the plastic lumber would be controlled by its summer strength and stiffness. The plastic lumber has a lower axial strength than does wooden lumber, by a factor of 2 to 5, depending on whether the axial strength is measured in compression, flexure or tension.

Larger cross-sections of the plastic lumber will be required to achieve the same strength, *i.e.*, it is not appropriate to simply substitute plastic lumber of the same size for wooden lumber in structural applications. Stiffness (modulus) of the plastic lumber is *much* lower than wooden lumber, by a factor of 20 to 40, depending on whether the modulus was measured in compression, flexure or tension. Because of the low modulus, columns made of plastic lumber may have to have much larger cross-sections than wooden lumber to prevent buckling.

On the positive side, the plastic lumber has higher shear strength than does wooden lumber, and is probably less likely to crack and split. It is an engineered material rather than a natural material, so the board to board structural properties will be more consistent. It can be fastened together using the same nails and screws as wooden lumber, and it holds the screws and nails very well. Tests indicate that the plastic lumber holds the fasteners significantly better than wooden lumber, and that for the same connection design the connections in the plastic lumber structures will be stronger than in the wooden lumber structures.

The plastic lumber exhibited significant creep in a 48 hour creep test, but the amount of creep would probably be acceptable for most outdoor decking applications. The density of the plastic lumber was very similar to wooden lumber, so dead load calculations and the weight of the structure will be very similar for wooden and plastic lumber. The slip resistance of the plastic lumber was lower than for wooden lumber. In the authors' opinion the plastic lumber is too slippery and should have a slip resistant cover or altered surface finish to be safe for use as decking material. Many companies use post consumer plastic waste to make the plastic lumber, so it reduces the amount of material that must be land filled. Plastic lumber is resistant to rot and insects without any chemical treatment. It does not leach hazardous materials into the environment like CCA or creosol treated lumber. It has the potential of being a good structural material and should be developed.

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