MECHANICAL PROPERTIES OF GRIDCORE^{TM} PANELS (FPL SPACEBOARD) MADE FROM COMPOSITIONS OF RECYCLED CORRUGATED, NEWSPRINT AND KENAF

C. Tim Scott
John F. Hunt
USDA Forest Service
Forest Products Laboratory[1]
Madison, WI 53705-2398

Tim Newburn
Julee Herdt
Colin Jessop
Gridcore Systems International
Long Beach, CA 90813

ABSTRACT

GRIDCORE^{TM} (FPL Spaceboard) is a three-dimensional, pulp-molded sandwich panel made by depositing and densifying a pulp slurry on a specifically designed resilient mold. Unlike low density pulp-molded products, GRIDCORE^{TM} panels can be highly densified to impart significant mechanical properties. This paper describes our initial efforts at producing GRIDCORE^{TM} panels from blends of old corrugated containers (OCC), old newsprint (ONP), and kenaf. The panels were tested for edge crush strength, flat crush strength, bending strength, and dimensional stability. The results indicate that desirable mechanical properties can be achieved from all panel compositions.

BACKGROUND

The development of new process technology to produce structural products from cellulose pulps has been an active area of research at the USDA Forest Service, Forest Products Laboratory (FPL). A decade ago, Setterholm (1) introduced the unique method of forming a three-dimensional, waffle-like structure from molded wood pulp. He called the board “Spaceboard” because of the open cells or “space” between the ribs of the “board” (Figure 1). At the time, Setterholm envisioned producing a Spaceboard panel that would have strength characteristics similar to that of corrugated boxboard but could be produced in a one-step forming process. Additionally, the process could accommodate underutilized fiber sources such as mixed hardwoods and wastepaper. These two goals set the stage for several breakthroughs in molded pulp processing technology at FPL. Subsequent process improvements were developed by Hunt, Gunderson, Gleisner, and Scott (2-4). One of these improvements was the development of a resilient mold containing an array of hexagonal (hex) pads. Spaceboard panels made from these hex molds results in the honeycomb rib structure shown in Figure 2.

In 1992, the Spaceboard patents (5-9) were licensed for specific fields of use in construction and furniture by Gridcore Systems International (GSI). A Cooperative Research and Development Agreement (CRADA) was initiated between FPL and GSI to support the transfer of Spaceboard technology to GSI. The hex mold concept was initially adopted because of the many desirable features of the honeycomb panels. A significant research effort was undertaken by GSI to produce a new hex mold that would accommodate their production and marketing needs. Spaceboard panels made from these molds became known as GRIDCORE^{TM} panels. In 1993, GSI was awarded a grant from the USDA Alternative Agricultural Resource and Commercialization Center (AARC) to explore the commercial potential of producing Spaceboard panels produced from kenaf fiber.

This report is a preliminary evaluation of the physical and mechanical properties of GRIDCORE^{TM} panels produced from OCC, ONP, and kenaf as part of the AARC-funded study. All panels were produced and tested at FPL as part of CRADA activities.

TESTS ON GRIDCORE^{TM} PANELS

Stock Preparation and Panel Production

For this study, hammermilled kenaf stalks were obtained from KENAF International and shipped to Sprout-Bauer for thermomechanical refining. The hammermilled stalks were soaked in water prior to refining, then fed into a pressurized double-disk refiner at 2.07 bar steam pressure and a 1.5-min retention. A 2% sodium hydroxide charge was added to the kenaf in the eye of the refiner. This first refiner pass resulted in a shive content of 39% at 653 Canadian standard freeness (CSF). A second refiner run was made in an atmospheric refiner to lower the shive content to 24% and freeness to 410 CSF. Both OCC and ONP pulps were produced by hydropulping each at 3% consistency and 60°C. Neither pulp was refined before use.

All GRIDCORE^{TM} panels were formed by the flow-through method of producing Spaceboard (2,5). This method incorporates an integrated mold in which the hexagonal pads are connected to a wire screen (Fig. 3). First, a pulp slurry at 1% con-

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sistency is added to the deckle box, as shown in Figure 3a. With the aid of an applied vacuum, the water is drawn through the screen. The wet mat is removed from the deckle box while still on the mold. A screen is then placed on the top surface (facing) and the mat is placed in a hot press. As heat and pressure are applied, the hexagonal pads compress and deform laterally, densifying the fiber web or "ribs" (Fig. 3b). Press conditions of 175°C and 690 kPa were used on all panels.

Finished panels were nominally 1.2 m by 2.4 m and 9.5 mm thick. Four pulp compositions were chosen for this study: 100% OCC, 100% kenaf, 50%-OCC/50%-kenaf, and 50%-kenaf/ 25%-GCC/25%-GNP. Both heavy (7.5 kg) and light (5.5 kg) panels were made from each composition. Each panel was cut into six segments. The segments were then paired and bonded rib-to-rib to produce a test panel, using polyvinyl acetate adhesive.

Tests on Mechanical Properties

Each test panel was cut into three 70-mm-wide strips for bending tests. The remaining 75-mm-wide strip was cut into 75-mm-square blocks for edge crush and flat crush tests and one 75-mm by 250-mm block for linear expansion measurements. All tests were implemented according to the appropriate ASTM standard protocol for sandwich panel construction.

Two bending tests were implemented to determine modulus of elasticity (MOE), modulus of rupture (MOR), and type of failure. A 457-mm span was used for a center-point load bending test, and a 686-mm span was used for the third-point load bending test. The width was chosen such that four ribs were aligned parallel to the long axis of the beam. The tests revealed that the MOE values range from 5 to 6 GPa (Table I) for panels tested at 50% relative humidity (RH) and from 2.5 to 4 GPa at 90% RH. Although most panel types failed in compression, the heavier, blend panels were susceptible to shear stresses and resulted in shear failures in the ribs, limiting the corresponding MOR values.

Edge crush tests were implemented to determine the edge compression strength of panel blocks. Both gross compression strength and facing stresses were calculated and are listed in Table I. We anticipated an orientation effect as a result of the hexagonal geometry of the ribs, but this was not apparent in the results. However, the rib structure did influence the type of failures observed, especially in the light panels. This effect was due to the lower density regions in the facing over the ribs.

Flat crush tests were implemented to determine the load bearing potential of the ribs. Table I lists the gross fail stress measured for each panel composition produced. These results show that panels made from 100% kenaf could sustain bearing stresses nearly 50% higher than 100% OCC panels. It is important to note, however, that bearing strength is directly affected by rib alignment. Strength values can be severely compromised if the ribs are even slightly misaligned. To determine the bearing strength of fully aligned panels, unbonded half-panels or subpanels were tested. These values are also listed in Table I.

Finally, each panel was tested for dimensional changes subject to a 60% variation in relative humidity (30% to 90% RH). Because of the susceptibility of fiber-based panels to moisture, particularly when no provision has been made to supplement hydroxyl bonding, it is important to characterize dimensional stability if structural applications are being considered. Linear expansion and z-direction expansion were measured for all panels (Table I).

CONCLUSIONS

Traditional pulp-molded products, such as egg cartons, are typically of low density and function primarily as cushioning for packaging. At the Forest Products Laboratory, the development of Spaceboard process technology has been an attempt to produce highly densified, three-dimensional structures from paper pulp. One of these structures is a GRIDCORE^{TM} panel. The hex mold configuration and process conditions used result in panel facings with specific gravities near 1. At these densities, significant internal bond strength is developed and mechanical properties suitable for structural applications can be achieved. For example, from bending tests at 50% RH, calculate MOE values ranged from 5 GPa for 100% OCC panels to 6 GPa for 100% kenaf panels. The MOR values range from 20 to 35 MPa for the same respective panels. These values are very near reported values for high density hardboard and above the geometric mean for high strength papers. Sheathing grade plywood, however, has about twice this strength. However, Spaceboard has less than one-half the basis weight of an equivalent thickness of plywood.

One of the most desirable features of the Spaceboard forming process, in terms of recycling, is the ability to tolerate "contaminated" fiber sources. The kenaf pulp used in this study had a rather high shive content (24%). This shive content is unacceptable for making paper but works well in Spaceboard. Therefore, pulps made from agricultural fiber sources such as kenaf need not be reduced to single fibers, reducing both the energy required to produce pulp and damage to fiber integrity. The ONP used in this study was not deinked. Drainage rates are an important aspect of the Spaceboard process and are affected by contaminate level and mold design. Provisions can be made to circumvent these problems.

Although our results show that the mechanical properties of Spaceboard may be suitable for structural applications, there are other significant issues that must be addressed before it can be used in these applications. Of utmost concern is the issue of durability. To meet code requirements, sheathing panels must pass a wet/redry cycle. Therefore, wet strength and stiffness must be imparted to the panels. Other concerns are fire resistance, pest and fungal resistance, and fastening requirements. These areas are the focus of continued research under CRADA activities with GSI.

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Table I - Physical and Mechanical Properties of GRIDCORE

	100% OCC	100% KENAF	50% KENAF + 50% OCC	50% KENAF + 25% OCC + 25% ONP
Basis Weight (kg/m2)	4.3	4.4	4.2	4.0
Thickness (mm)				
full panel	17.6	17.9	17.4	18.2
facing	1.85	1.96	1.83	1.78
rib	0.43	0.43	0.30	0.38
Density (g/cc)				
full panel	0.24	0.25	0.24	0.22
facing	1.16	1.12	1.15	1.12
3rd point Bending @ 50%RH				
MOE (GPa)	5.7	6.2	6.1	5.8
MOR (MPa)	27.2	34.7	25.3	24.1
failure mode	comp	comp	shear	shear
Centerpoint Bending @ 50%RH				
MOE (GPa)	5.4	5.8	5.7	5.6
MOR (MPa)	24.3	35.7	27.1	29.3
failure mode	comp	comp	shear	comp
Centerpoint Bending @ 90%RH				
MOE (GPa)	3.2	4.3	3.3	4
MOR (MPa)	12.9	24	16.1	19.3
failure mode	comp	comp	shear	comp
Edge Crush Test @ 50%RH				
gross fail stress (kPa)	3.1	4.8	4.3	3.6
facing stress (MPa)	14.8	21.9	20.3	18.5
Edge Crush Test @ 90%RH				
gross fail stress (kPa)	2.3	4.6	3.3	2.9
facing stress (MPa)	11.9	21.5	15.9	14.6
Flat Crush Test @ 50%RH				
gross fail stress (kPa)				
combined panel	403	442	280	338
sub-panel	398	634	470	521
Linear Expansion (%)	0.15	0.21	0.18	0.16
Thickness Swell (%)	1.5	1.5	1.4	1.3

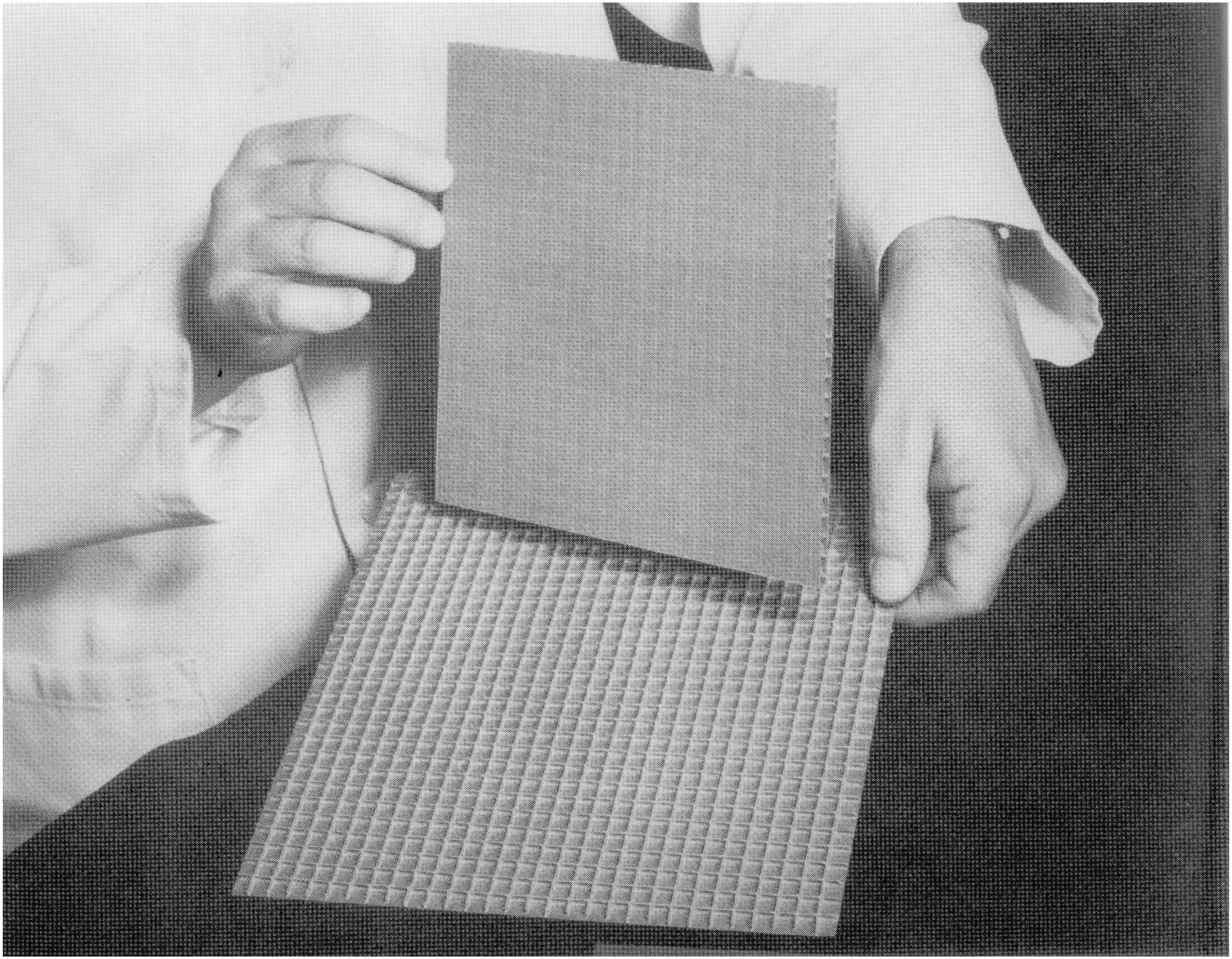

Fig. 1. The Spaceboard pulp-molding process is used to form a waffle-like, open-cell board. Two boards are bonded rib-to-rib to produce a closed-cell panel. The panel shown has properties similar to that of C-flute corrugated board.

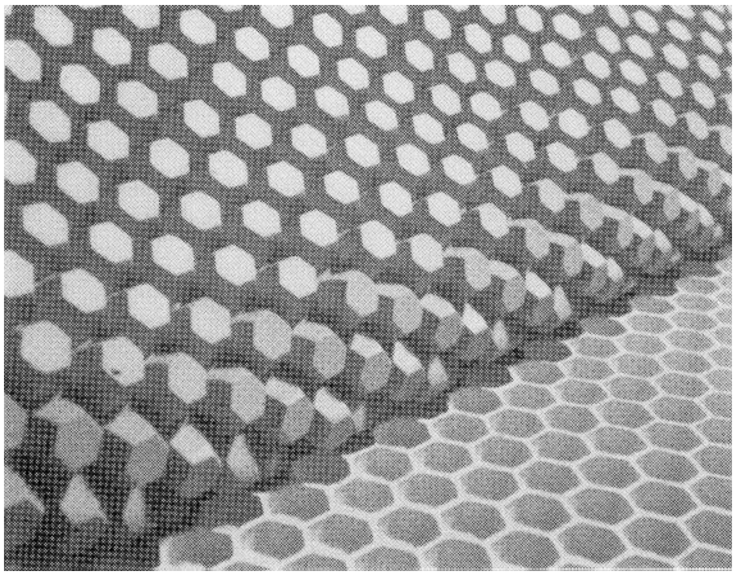

Fig. 2. GRIDCORE^{TM} hex mold and panel.

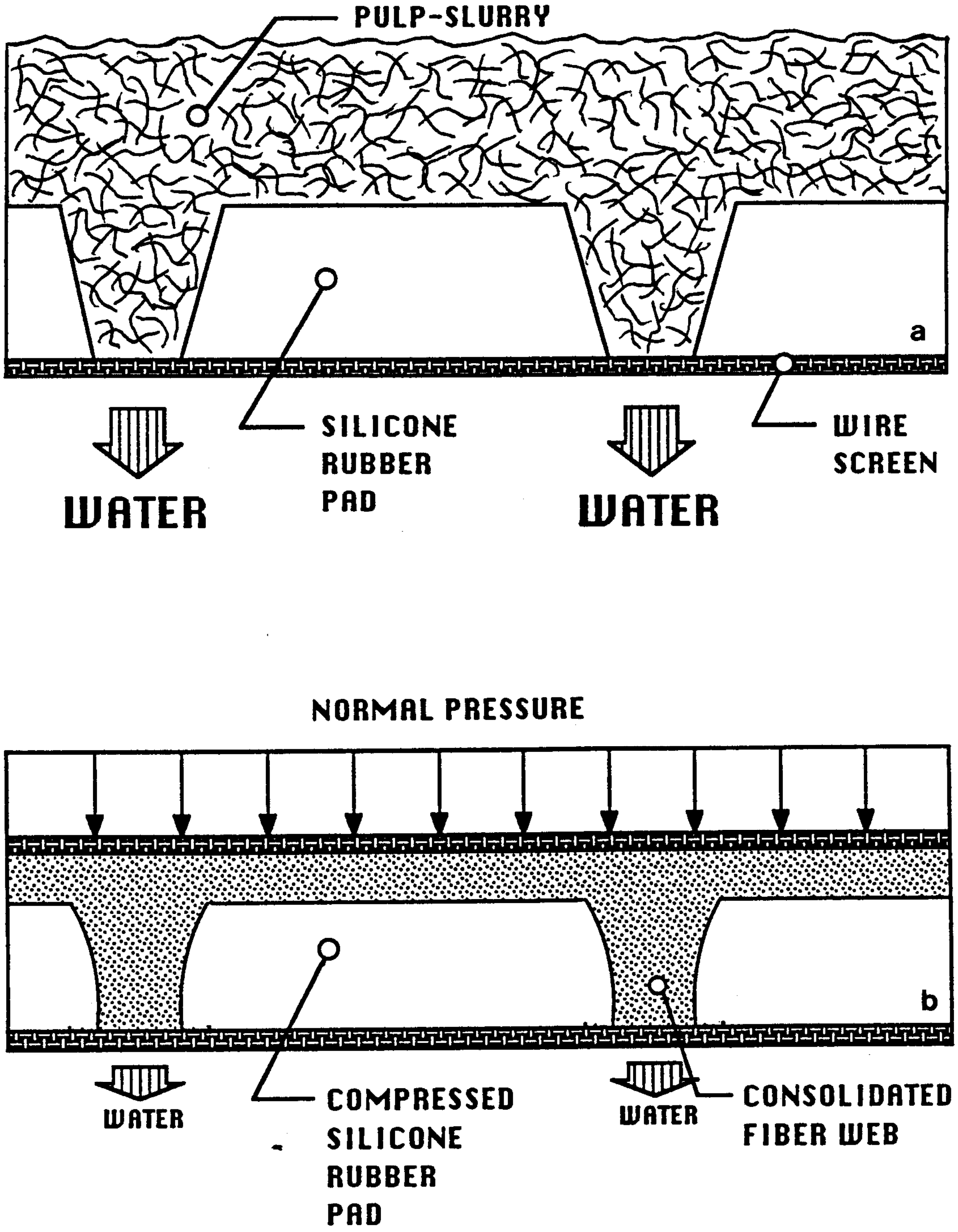

Fig. 3. Spaceboard forming process: (a) fiber is deposited on the mold as water drains through the wire screen; (b) hexagonal pads deform laterally, densifying the webbing when normal pressure is applied.

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Technologoy Park/Atlanta
P.O. Box 105113
Atlanta, GA 30348-5113, USA