

VIABILITY STUDY FOR REPLACEMENT OF CAST IRON LIDS FOR PLASTIC WOOD

Fernanda Soares Marin**Advisor****Daniel de Almeida Silva Gonçalves****ABSTRACT**

Due to the need to reduce the amount of plastic waste produced daily, it is necessary to take a new destination for these residues, to take advantage of it in the least aggressive way to the environment. A possible solution is the plastic wood manufacturing, a composite similar to the natural wood, however, manufactured starting the plastic waste. Since the greater the use of this material, the greater the amount of waste removed from the environmental, this article has as objective analyze the viability from your use in manhole covers, now made off cast iron. For this, resistance tests were performed in the material to analyze whether it meets standard requirements. After results evaluation, it can be concluded that the most recommended material remains cast iron.

Keywords: Plastic Wood. Manhole Covers. Recycling.

1. INTRODUCTION

One of the most addresses issues in recent years in the technical and academic environment is sustainability. This, among so many subjects, deals with the preservation of the environment, as well as pollution and the enormous amount of waste produced daily in the world. One of the most harmful residues is the plastic, because, in addition to its deterioration difficulty, when unduly dumped, they can be destined to streams causing floods, or in seas and oceans, destroying biomes. Even when correctly discards, these residues takes up a lot of space in dumps and landfills.

An attempt to solve the problem is to give a different destination to these residues. A choice that is currently being adopted in Brazil is the plastic wood manufacturing, a polymeric composite similar to natural wood which is not sustainable only to avoid deforestation but also to reduce the waste plastic amount from the environment.

Between your usual applications as a natural wood replacement, there is the use as manhole covers which, for been made by cast iron, are often stolen for sales as feedstock.

Because of this, the present article aims to analyze the feasibility of using plastic wood in manhole covers, observe the features, analyze its behavior and check if exist some class of lids in which the material could be used.

2. THE PLASTIC WOOD

The Biosynthetic Wood, better known as Plastic Wood, is a composition of polymers and wood scraps. As much as received its name, the plastic woods are:

manufactured products with plastic content higher at 50% by weight and generally have a rectangular cross-section and show typical dimensions from the industrialized wood products. (OLIVEIRA, 2013 apud SERVIÇO BRASILEIRO DE RESPOSTAS TÉCNICAS, 2007. p.3),

The plastic is a major feedstock, with a smaller portion of wood addition resultant by industry wood scraps, as the hardwood dust.

The plastic wood can received another kind of composite besides the wood powder, with the main function purchase mechanical efforts resistance (Mesquita, 2013). However, the major differential is the plastic wood is recyclable and sustainable. In addition to acquiring a visual very close to or equal to the common wood (Figure 1), the main component from Plastic Wood in Brazil comes from garbage (Pinto, 2007) and is totally renewable in its manufacture.

Figure 1 – Rectangular sample of Plastic Wood



Source: Ecocasa (2001)

2.1 Plastic Wood History

According to Pinto (2007), the first productions of Plastic Wood began in the 1970s, using the garbage as raw material, already evidencing the necessity to recycle the waste produced by human beings. But only in the 1990s the plastic wood

gained notoriety and started to be manufactured by the USA (Mundo Sustentável, 2010), arriving in Brazil in the same decade, but in a more discreet way.

In an interview to O Globo Online (2008), the professor Elen Pacheco, developer of the plastic wood study in Brazil along with professor Eloisa Mano, said that “the plastic wood study became from the concern in increased the cycle life from post-consumption plastic, fossil product and minimize the issues referring to inappropriate discard”. In this way, in the 1990s the Macromolecules Professor Eloísa Mano Institute (IMA) from Universidade Federal do Rio de Janeiro (UFRJ) started the first studies about plastic wood in Brazil, which covers the physical and mechanical properties from the wood (Oliveira, 2013) and it was named IMAWOOD because of the translate from the English means “wood from IMA” (Motta, 2008).

2.2 Plastic Wood Manufacturing

2.2.1 Composition

The plastic is a compound of a polymers junction that made huge molecules chains. Already the polymers are compounds by the union from little molecules chains, known as monomers, which are characterized for been molded under pressure, with chemical reactions or heat (Guimarães, 2018).

It can divide the plastics into two types:

- **Thermosets** – they do not melt and cannot be molded again, but they can be sprayed and tapped as loads and energy recovery.
- **Thermoplastics** – a group which the plastic wood fits – are those that soften when heated, getting new solid forms when colds.

The softening and cooling process of thermoplastics can be repeated several times, making it one of the reasons why the plastic wood is so sustainable because your manufacturing scraps and waste are reheated and sent back for the beginning of the manufacturing process. The thermoplastics that can be used in the plastic wood are (Guamá, C. 2008):

- **Polyethylene Terephthalate (PET)** – used in packaging of soft drinks, juices, and some cleaning products;
- **High-Density Polyethylene (PEAD)** – used in making crates for drinks, bottles of alcohol, chemicals, and hygiene and household cleaning;

- **Low-Density Polyethylene (PEBD)** – employed in food packing, industrial and garbage bags;
- **PVC or Polyvinyl Chloride (V)** – used in shoes, in pipes and connections for water and the coating of electric cables;
- **Polypropylene (PP)** – used in margarine jars and disposable syringes;
- **Polystyrene (PS)** – used in disposable cups, insulating plates, and school supplies;
- **Other** – such as plastic resins used in special engineering plastics, CDs, and computer bodies.

Besides the plastics, some types of materials such as synthetic fibers and vegetable fibers can be added to plastic wood (Mesquita, 2013). According to Fiorelli (2005), the main synthetic fibers added to polymers are glass fibers, Kevlar fibers (aramid) 49, and carbon fibers.

Each fiber has its specific characteristics. Glass fibers are cheaper than other synthetic fibers, in addition to having a low coefficient of thermal expansion and good mechanical properties. Kevlar fibers, in turn, have the highest strength/density on the market. Carbon fibers, on the other hand, can be manufactured with different configurations of resistance and modulus of elasticity, depending on the type of treatment it receives in its manufacture. (Fiorelli, 2005; Mesquita, 2013).

Vegetable fibers, as the name says, are designated as particles and bundles of stems or sheets of fibers. They are sisal, coconut shell, jute, bamboo, sugar cane bagasse, banana tree, wood particles.

In general, vegetable fibers have been studied for application in polymers, although they are already being used in Brazil, for applications that require more effort. The studies of mechanical properties have shown satisfactory results, but it is worth mentioning that improvements and research are still needed. Vegetable fibers have some disadvantages such as the possibility of interacting with water, being attacked by fungi and bacteria and low thermal stability, but their advantages are due to being cheap, renewable and, when applied to plastic wood, the polymeric covering reduces the risk of attacks by fungi and moisture, depending on the fiber applied. The growth of vegetable fibers in the market is also an advantage, as it serves small markets and, consequently, benefits consumers and buyers who receive more varieties of products and costs (Mesquita, 2013).

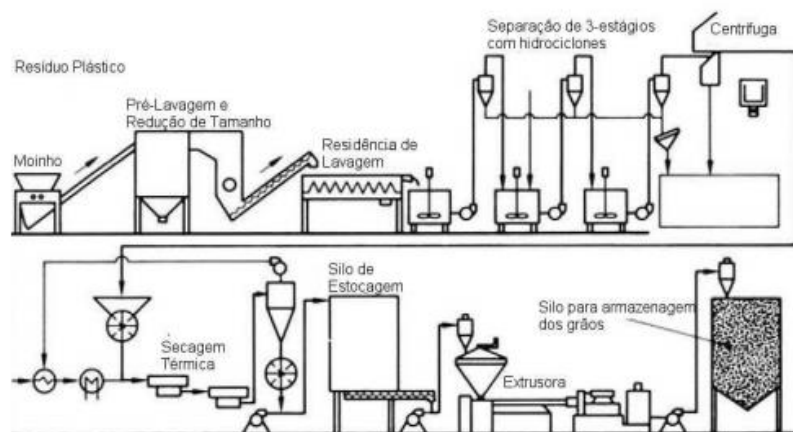
2.2.2 Manufacturing Methods

Recyclings that occurs worldwide, standardized by the American Society for Materials Testing (ASTM), are divided as follows:

- **Mechanical Process** – Primary recycling and Secondary recycling
- **Chemical Process** – Tertiary recycling;
- **Energetic Process** – Quaternary recycling.

The process used in the production of plastic wood in Brazil is mechanical and they are founded in the following ways: collection and separation, grinding and second washing, extrusion and cooling, and molding (Oliveira, 2013).

Figure 2 – Recycling Mechanical Process



Source: (ESPÍNDOLA, 2004)

- **Collection and Separation** – The collection of plastic waste is the first step in the plastic wood production process. If carried out before going to the landfill, the plastic comes cleaner and optimizes the plastic wood manufacturing process. Any type of material can be used, but the most used are low-density polyethylene and high-density polyethylene. The separation can be done by gender or by color, white and colored, for the option of manufacturing light woods (Guamá, 2008).
- **Grinding and Second Washing** – Grinding comes right afterward, intending to grind the collected plastic and form granules called pellets. The second wash only occurs if there are impurities (Oliveira, 2013; Guamá, 2008; Nazário et al., 2016).

- **Extrusion** – This is the stage where the plastic is reprocessed inside a machine called an extruder, in which it can have different sizes. The plastic is melted and homogenized, in which the step consists of forcing the material through an orifice. Pigments are commonly added in this step, but they can also be placed with the granules (Oliveira, 2013).
- **Cooling and Molding** – After extrusion, the material goes through a cooling process, consequently, have it the plastic wood. Most plastic woods companies obtain the piece in the form of a log, but the necessary tools can be applied to obtain the shape they desire (Oliveira, 2013; Guamá, 2008; Nazário et al., 2016).

2.2.3 Plastic Wood Production Sites

The largest world market for plastic wood is the United States, but here in Brazil, in addition to the samples manufactured at IMA to study the properties of plastic wood, manufacturing for commercial use is still a small market.

According to Guamá (2008), one of the most important companies in the production of plastic wood is Cogumelo, which is located in Campo Grande, Rio de Janeiro. There are also some factories such as Ecoblock, which is located in Belo Horizonte, Minas Gerais; Reciplast, in Guarulhos, São Paulo. In Rio de Janeiro the Market is bigger and more comprehensive, with companies like Ecowood and PolyRio Polímeros.

2.3 Application characteristics of Plastic Wood

Due to its characteristics, it is still not heard today about the use of plastic wood as a structural element of a building, however, it is already widely used in some simpler uses of natural wood, such as fences, benches, dumpsters, pallets, as well as in some rustic furniture and mainly on decks (Figure 3), the last being the first application of plastic wood, contemplating, according to Oliveira (2013), 30% of the decks and balconies built in the USA.

Figure 3 - Deck around a pool built in Plastic Wood



Source: InBrasil (2018)

Besides the more conventional use of natural wood, plastic wood has been used in applications that suffer greater demands, replacing railway sleepers and, in some places, manhole covers (Figure 4), which are traditionally made of cast iron (Paula, 2008).

Figure 4 – Manhole Cover made from Plastic Wood



Source: Policog (2018)

Plastic wood looks similar to natural wood, but it is waterproof and can be cleaned more easily since water and soap can remove its impurities. Because its main raw material is plastic, it has long durability and unlike natural wood, does not require periodic maintenance (Silva, 2016).

It is a material that is not affected by mold and pests in general, presents resistance to humidity, does not rot, does not crack and does not loosen splinters, because its fibers are fused with the polymer during manufacture. Since it comes pigmented, it does not require sanding, sealing, painting, and any other type of treatment, being ready for installation. Its workability is similar to that of natural wood,

using the same tools to be screwed, painted, glued, and waxed, according to its final destination (Guamá, 2008).

According to Guimarães (2018), for every 700 kg of material produced, a large adult tree is spared, so it is an easier material to obtain since it does not require environmental certification. Also, it cools faster when exposed to the sun than natural wood and, because it is completely recycled, it does not have the harmful substances found in treated wood, and can still be processed again, which makes it a recyclable.

Like the wood found in nature, the polymer-wood composite is an excellent thermal and electrical insulator and still absorbs great vibrations, which makes it ideal for use in railway sleepers (Figure 5). It is less slippery than natural wood, which is one of the reasons for its use in pool decks.

Figure 5 – Plastic Wooden Railway Sleeper



Source: Salles (2009)

Indirectly, plastic wood contributes to the preservation of forests, since the raw material for a range of products ceases to come from natural trees, and collaborates directly with the reduction of plastic waste in the environment since it is used in its manufacture (Ohara, 2011).

It is a positive chain reaction because with the decrease in plastic waste, which in addition to being produced on a large scale takes years to deteriorate, there will be an increase in the useful life of landfills, as well as savings with the recovery of the impacted area, reduction of expenses with the cleaning of these residues when disposed of incorrectly and with public health since with the reduction of pollution, the proliferation of diseases tends to be less. Another benefit would be the movement of

the country's economy, generating jobs and income for recyclable material collectors (Spinacé, 2005).

When compared to natural wood, plastic wood has good resistance to compression and shear, however, special attention is needed in the choice of fibers that will be used as filler since they will change the physical, chemical, and mechanical properties of composites. (Oliveira, E. 2013). Per smaller that can be the changes in fibers, it reflects on the material's performance. (Table 1).

Table 1 – Plastic Wood Resistances

Resistência	Rewood	Ecwood	Star Deck
Compressão	35,92 MPa	39,11 MPa	31,00 MPa
Tração	9,13 MPa	19,48 MPa	9,00 MPa
Flexão	36,468 MPa	113,9 N	9,6 MPa
Absorção de Água	0,13%	0,23%	0,09%

Source: Rewood, (2018); Ecwood, (2019); Star Deck, (2018)

Given all the benefits that plastic wood portrays compared natural wood, the environment, and even the economy, it is still not so popular due to its high initial investment, a fact that occurs both due to the public's unknown the product and, mainly, for the high value to obtain its raw material since the selective collection is quite expensive, about 5 times higher than the common collection. (Pinto, 2009)

2.4 Physical and chemical characteristics of Plastic Wood

To find standardization among the results obtained through the tests, parameters given through regulatory standards are followed, which attest to the quality, safety, and product information.

The tests carried out on plastic wood are characterized by the Brazilian Association of Technical Standards (ABNT), the American Society for Materials Testing (ASTM) and the International Organization for Standardization (ISO), which aim to guarantee international standards for physical and chemical tests through following standards:

- ASTM - D638 for strength and traction module;
- ASTM - D790 for strength and flexion module;
- ASTM - D695 for compression testing;
- ASTM - E2550 for thermogravimetric (TGA);

- ASTM – F2778 for FTIR.

In tests applied to the composition of plastic wood to analyze its mechanical performance, it was observed that the more wood fibers are added to the composition, the greater the water absorption, flexural modulus, and strength in the material. As for the modulus of elasticity and tension at the break, the material behaves in an inverse way, that is, there is a drop in mechanical property with increased addition of these fibers (Guimarães, 2013).

One way to solve this is to put additives in the composition to improve the homogenization of the material and the mechanical performance since the type of fiber, quantity, and size directly influence the mechanical properties. The properties of plastic wood, such as thermal conductivity, have stability of up to 250° C and is a material very resistant to water absorption. When compared to natural wood, they have a lot of rigidity, low density, durability when exposed to the weather for 11 years without changes in their mechanical properties. The chemical structure is responsible for making this product recyclable and has a great influence on its final performance. (Guimarães, 2013)

2.5 Costs

Since it is a material unknown to the general public, plastic wood still raises doubts about its price compared to natural wood. Because it is an industrialized product, the manufacture of plastic wood requires a production process that involves machinery with the high cost to obtain a high-strength material in addition to the difficulty in obtaining its raw material. According to Almeida (2013), plastic wood can cost up to 40% higher than natural wood.

3. METHODOLOGY

To achieve the purpose of this article, characterization and resistance tests were performed using three plastic wood profiles provided by the company Ecowood Industrial Ltda.

The profiles had the dimensions 600 x 100 x 20 mm, 600 x 100 x 25 mm, and 600 x 100 x 300 mm and were made of polypropylene with the addition of inorganic fillers (Figure 5). Because it is a polymer, the tests were carried out according to ASTM standards in the laboratories of Insper – Institute of Education and Research,

University of Mogi das Cruzes – UMC, Campus Villa Lobos, and IPT – Institute of Technological Research.

Figure 6 – Plastic Wood Profile used in the tests



3.1 Chemical characterization tests

3.1.1 FTIR test

The FTIR test was performed according to ASTM F2778 – 09 (2015) – Standard Test Method for Measurement of Crystallinity Percentage of Polyetheretherketone (PEEK) by Infrared Spectroscopy with Fourier Transform of Specular Reflectance (R-FTIR). The test consists of an infrared ray that passes through a sample of the material, generating a spectrum of the molecular structure of the chemical compound. Through this spectrum, it is possible to identify the composition of the material, analyzing the behavior of the chemical groups present in the molecule. Due to its difficulty in realization and logistics, the FTIR test was performed by the laboratory of Insper Instituto de Ensino e Pesquisa, which provided the results.

3.1.2 TGA Test

For the test, the ASTM – E2550 – 17 – Standard Test Method for Thermal Stability by Thermogravimetry was used, and the same was carried out in the IPT laboratory. The purpose of the test is to analyze whether there are inorganic loads in

the material by previously weighing the powder sample, followed by heating it, starting at room temperature, with a growth rate of $10^{\circ}\text{C} / \text{min}$.

A graph of curves is generated by which it is possible to analyze any reaction observed, such as a change in mass or decomposition of the composite. Due to the logistical infeasibility to perform the test, the same was done by the IPT, which provided the results.

3.2 Mechanical characterization tests

3.2.1 Tensile Test

The tensile test was carried out in the UMC laboratory, Campus Villa Lobos, according to the ASTM – D638 – 14 – Standard Test Method for Plastic Tensile Properties. For the test, five specimens were cut with a circular saw according to the Type III of the standard, machined in a Diplomat 3001 tool mill, and, later, in a Diplomat 3001 drill machine.

The bodies were sanded with a file and placed in the universal testing machine INSTRON EMIC 23 – 100 to perform the test. In it, the ends of the specimen are attached to the claws of the machine, which performs the traction movement on them, applying a gradually increasing load, initially at 0 N (Newton), at a speed of 5 mm/min (Figure 7). When the strength limit of the specimen is reached, the machine stops exerting a lot.

Figure 7 – Tensile Test

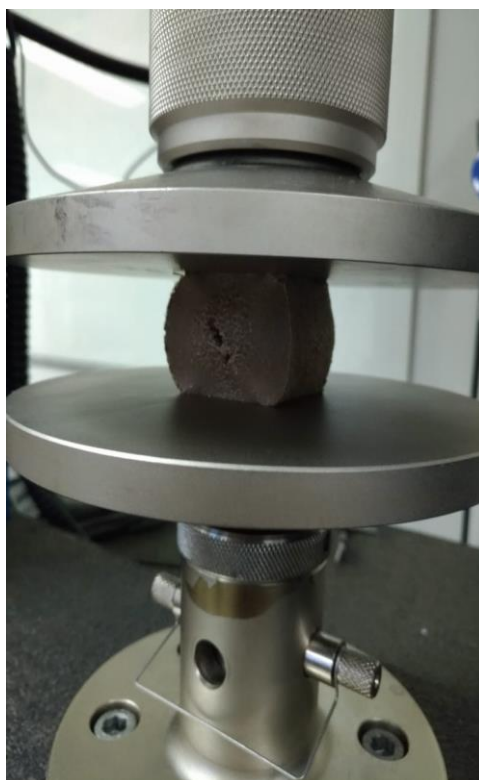


3.2.2 Compression Test

The compression test was carried out following ASTM – D695 – 15 – Standard Test Method for Compressive Properties of Rigid Plastics, in the UMC laboratory, Campus Villa Lobos. For this, five specimens were cut according to article 6.2 of the standard, in dimensions 60 x 30 x 30 mm, using the saw arch and machined in a Diplomat 3001 tool mill. Then, the bodies were sanded with file and placed in the universal testing machine INSTRON EMIIC 23 – 100.

The test consists of including the specimen by applying a load gradually, starting at 0 N at a speed of 1.0 mm/min (Figure 8). At a given moment, the machine stops applying the load to the specimen, indicating that the body reached the resistance limit.

Figure 8 – Compression Test



3.2.1 Flexion Test

The standard used for the test was ASTM – D790 – 17 – Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastic and Electrical Insulating Materials, and the same was carried out in the UMC laboratory, Campus Villa Lobos. Five specimens were cut with a saw arch, in the dimensions of 20 x 5 x 120 mm.

After being cut, they were machined in a Diplomat 3001 tool mill and placed in the universal testing machine INSTRON EMIC 23 – 100 for a three-point bending test using the crosshead position for measuring deflection.

During the test, the ends of the specimens were supported on two lower supports of the machine, while third upper support applies a load starting at 0 N gradually in the center of the part at a speed of 0.01 mm/min (Figure 9), thus generating the flexion movement. Upon reaching the strength limit of the specimen, it breaks and the machine stops applying load.

Figure 9 – Flexion Test



3.2.4 Izod Impact Test

For the test, the standard ASTM – D256 – 10 – Standard Test Methods for Determination of the Resistance of Plastics to the Impact of the Izod Pendulum was carried out in the IPT laboratory. For the test, a rectangular specimen has one of its ends fixed to the machine, maintaining another free. The pendulum arm comes against a sample, at a weight determined by the standard, breaking the specimen. The machine measures impact resistance that the specimen support. Due to its difficulty in realization for testing, the same was done by the IPT, which provided the results.

3.3 Applicability Tests

To analyze which is the best application for the material, two tests were carried out according to the NBR 10160 standard, of the residual arrow and load/control, to check which resistance class the cover fits best. Table 5 of the standard that determines the minimum loads for each cover class was used as a parameter for the control load.

Table 1 – Minimum loads for each cover class

Dimensão da cota de passagem (CP)	Classes de tampão ou grelha (Grupo)	Cargas de controle kN
$CP \geq 250$ mm	A 15	15
	B 125	125
	C 250	250
	D 400	400
	E 600	600
	F 900	900
$CP < 250$ mm	Todas as classes	Carga de controle $\times \frac{CP}{250}$

For residual arrow, Table 7 of the standard that regulates the maximum allowable arrow for each cap class was used.

Table 2 – Maximum allowable arrow for each cap class

Classe kN	Flecha residual admissível mm	
A 15 e B 125	$1/100 CP^{1)}$	
C 250 a F 900	$1/300 CP^{2)}$ Com a segurança garantida conforme 5.2.6 a) ou c)	$1/500 CP^{3)}$ Com a segurança garantida conforme 5.2.6 b)
¹⁾ $\frac{CP}{50}$ e $CP < 450$ mm. ²⁾ Máximo 1 mm, se $CP < 300$ mm. ³⁾ Máximo 1 mm, se $CP < 500$ mm.		

The standard states that the tests have to be carried out with the cover already installed on the site, but, since the manufacture of the cover is still unviable in this study phase, a simulation of the tests on a smaller scale was carried out in the UMC laboratory, Campus Villa Lobos.

To simulate both tests, a cylindrical specimen, 60 mm in diameter, was cut with a circular saw, corresponding to the 0.60 m in diameter of item 5.2.2 of the standard and 30 mm in thickness.

All dimensions of the specimen were proportionally reduced on a 1/10 scale, always adopting the standard as a reference. Just like as the applied forces required during the tests, they were also reduced by the same 1/10 scale, to simulate a prototype of the cover in its real size, with the thickness in real size being equivalent to 30 cm. The specimen was manually machined with a file and, as finishing, a TM – 360 Lathe was used.

In parallel to the body, a 60 mm diameter metal ring was made, cut with a circular saw, and machined in a lathe. A metal disk 25 mm in diameter and 20 mm in thickness was also used (Figure 11). A controlled load of 40 kN was admitted for the tests.

Figure 11 – Final specimen and items used in the test



3.3.1 Residual Arrow Test

For the performance of the test, the metal disk was placed over the center of the specimen, this fitted in the universal testing machine INSTRON EMIC 23 – 100. A load of control was applied increasingly and uniformly, compressing the disk against the specimen at a speed of 1 kN/s, and, when the value of 2/3 of the control load was reached, all the applied load was removed. The process was carried out five times, after which the final value of the arrow in the geometric center was measured.

3.3.2 Control Load Test

In the control test, the specimen used is the same as the previous item, as well as the execution process. The metal disk is pressed against the wooden body by applying a gradually increasing load, at a speed of 1 kN/s (Figure 12), but this procedure is performed only once for thirty seconds.

Figure 12 – Test performance



4. RESULTS AND DISCUSSIONS

After performing the tests and collecting data, it was possible to achieve the following results.

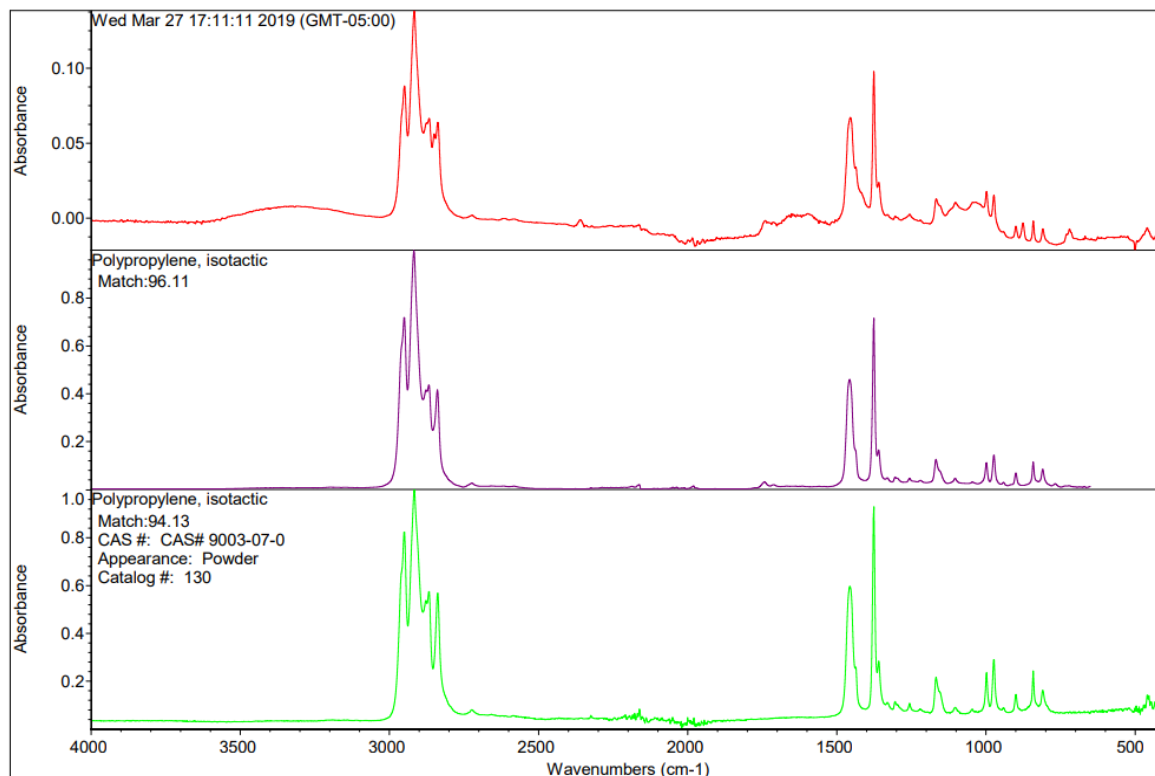
4.1 Chemical characteristics of Plastic Wood

4.1.1 FTIR

The FTIR uses infrared rays, where the vertical axis of the graph shows the absorbance capacity of infrared radiation waves in the sample and the horizontal axis the number of infrared radiation waves applied. Each peak corresponds to the vibration or elongation of chemical groups present in the molecule. According to the spectrum, it is possible to define the molecular structure of the chemical compound. Consequently, it is possible to say which molecule or macromolecule the sample is about.

The FTIR of the material in question shows that the polymer used is polypropylene (PP), as shown in Figure 13, which presents different analyzes of the same sample. Below the spectrum follows the name of the composite detected in each analysis.

Figure 13 –FTIR test results



Search results for: Wed Mar 27 17:11:11 2019 (GMT-05:00)
Date: Wed Mar 27 17:14:59 2019 (GMT-05:00)
Search algorithm: Correlation
Regions searched: 3495.26-649.90

Search results list of matches

Index	Match	Compound Name	Library Name
1	2818	96.11 Polypropylene, isotactic	HR Comprehensive Forensic FT-IR Collection
2	67	94.13 Polypropylene, isotactic	HR Spectra Polymers and Plasticizers by ATR
3	324	89.05 Polypropylene + poly(ethylene:propylene)	HR Hummel Polymer and Additives
4	2820	89.04 PolyPropylene, Polysciences	HR Comprehensive Forensic FT-IR Collection
5	3309	88.56 Solar Active Polypropylene	HR Comprehensive Forensic FT-IR Collection
6	2689	88.09 Poly(Propylene-Ethylene) Outdoor Carpet	HR Comprehensive Forensic FT-IR Collection
7	2232	87.68 Olefin Carpet (simulated wool)	HR Comprehensive Forensic FT-IR Collection
8	867	87.66 Concrete Reinforcing Fiber (slit film polypropylene+poly(eth	HR Comprehensive Forensic FT-IR Collection
9	2810	87.59 PolyPropylene Film, Drawn 100% (stretched)	HR Comprehensive Forensic FT-IR Collection
10	67	87.54 Polypropylene, isotactic	HR Spectra Polymers and Plasticizers by ATR - corrected

Each polymer has its specific spectrum, with only a few variations in the waves, the spectra presented are characteristic of the polypropylene material, that is, they prove that the material is PP. If the spectra are analyzed in detail, it is possible to perceive small variations in the waves, but they have the same visual characteristics.

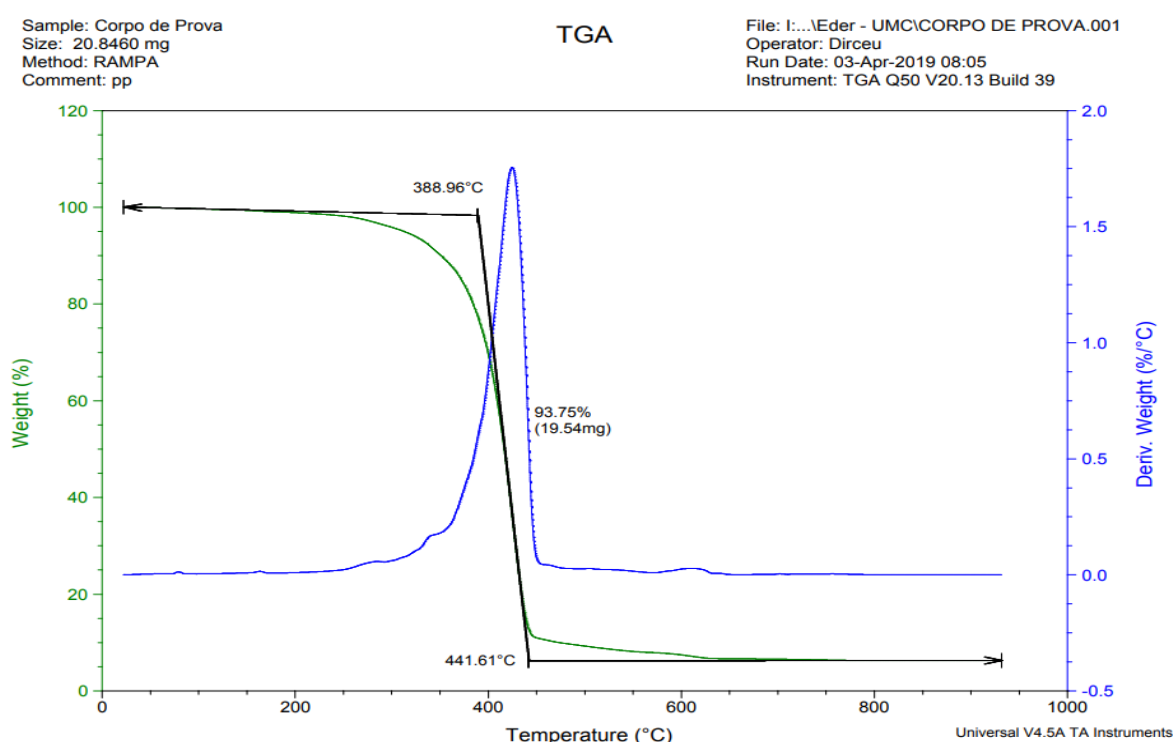
PP is used in jars such as margarine, not being a polymer that has great mechanical resistance.

4.1.2 TGA

The TGA is done to identify if there is any inorganic charge in the material, that is, lower quality material, such as calcium carbonate, which usually exists when there is an intention to cheapen the product.

The TGA result showed that the sample, when subjected to a temperature of 388.96°C, started to degrade and, upon reaching 441.61°C, stabilizes the degradation (Figure 14).

Figure 14 – TGA Results



The polymer has approximately 5% inorganic load, which is where the degradation line stabilizes, as shown in Graph 2. This load, in addition to cheapening the material, negatively alters its mechanical characteristics, decreasing its resistance.

4.2 Mechanical characteristics of Plastic Wood

4.2.1 Tensile Test

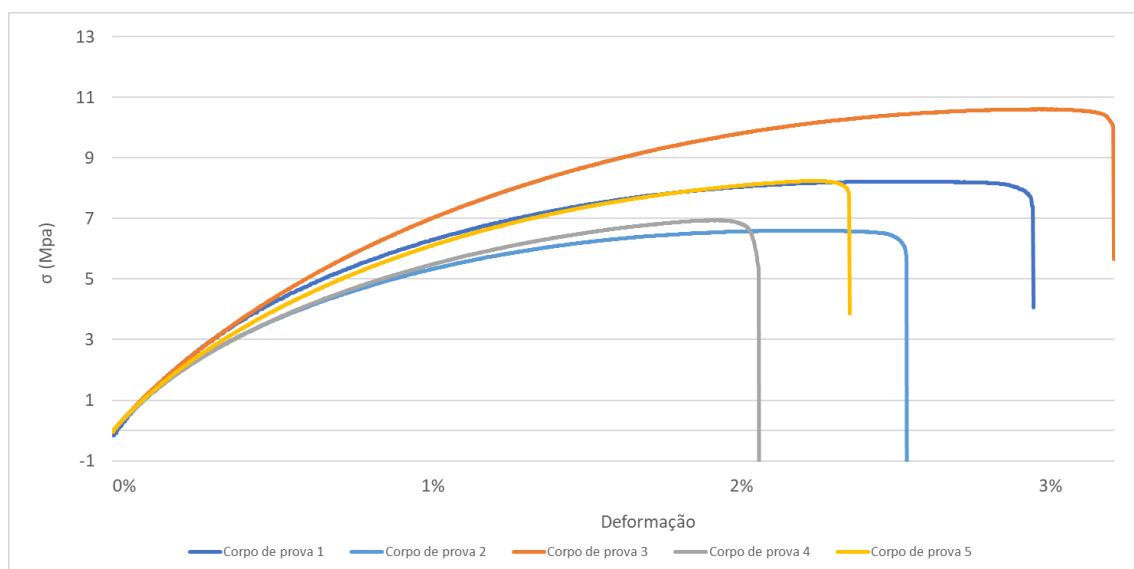
The test results are shown in Table 2, with five different specimens. Both had a maximum mean tension of 8.105 MPa.

Table 2 - Tension x Tensile Deformation

Corpo de Prova	Tensão Máxima (MPa)	Deformação Máxima (%)
1	8,224	2,983
2	6,579	2,643
3	10,592	2,487
4	6,908	2,122
5	8,224	2,391
Média	8,105	2,525

The standard deviation of the tension is 1,579 MPa. The average maximum deformation was 2.525% until the moment of rupture. The curve in Figure 15 shows the moment of the rupture of the specimens.

Figure 15 – Tension x Tension Deformation Chart



The specimens behave in such a way that they present relatively close results, according to the standard deviation presented, and none of them were discarded. The average value of 8,105 MPa acquired in tests carried out that the material has little wear resistance, cannot be used in applications that require such a large-scale mechanical effort.

4.2.2 Compression Test

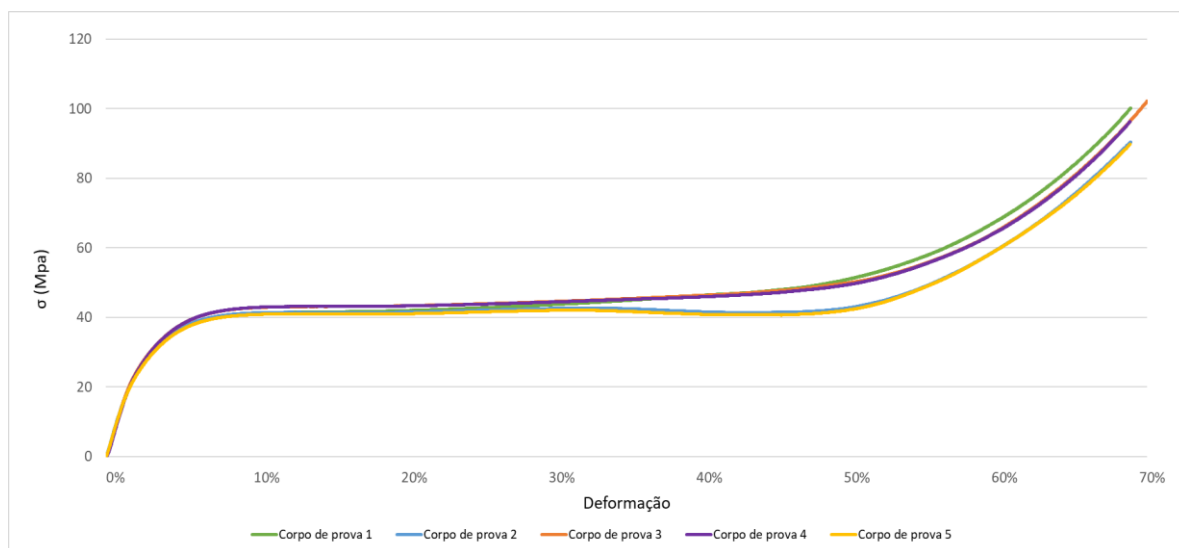
The test results showed little variation between the specimens, with an average of 44.379 MPa (Table 3). The standard deviation of the tension is 2,971 MPa.

Table 3 - Tension x Compression Strain

Corpo de Prova	Tensão de Deformação Elástica (MPa)	Deformação (%)	Tensão Máxima (MPa)	Deformação Máxima (%)
1	46,624	41,492	100,133	69,417
2	41,583	46,526	90,456	69,433
3	47,242	44,150	102,133	70,550
4	45,627	38,726	96,311	69,400
5	40,817	44,267	89,867	69,417
Média	44,379	43,032	95,750	69,643

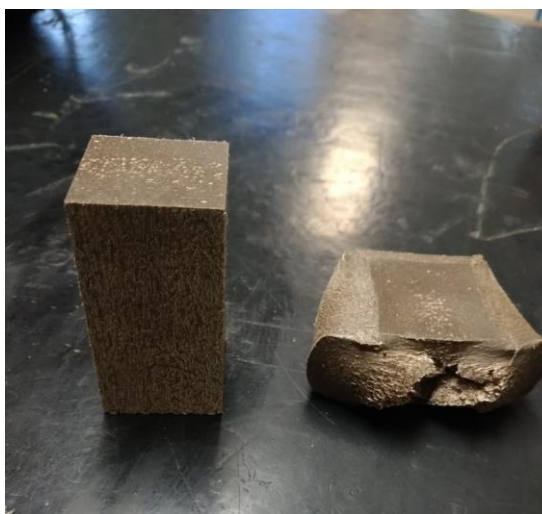
The values obtained after the elastic deformation, which correspond to the rising curve of the graph, cannot be used, as there was a change in the area of the specimens. The average maximum deformation was 69.643%, but the bodies did not reach rupture until 105.56 MPa, which is the limit of the machine (Figure 16).

Figure 16 – Compression Tension x Strain Graph



The rupture occurred only on the faces that were subjected to cutting (Figure 17).

Figure 17 – Specimen before and after the Compression Test



As shown in Figure 16, all specimens had very similar behaviors, which provide more reliability in the tests performed.

As none of the five specimens were completely broken, the compression analysis was carried out on the value of 44.379 MPa, which is a very good tension value, especially when dealing with a polymer. Given the results achieved, the material may be subjected to greater compression demands compared to traction.

4.2.3 Flexion Test

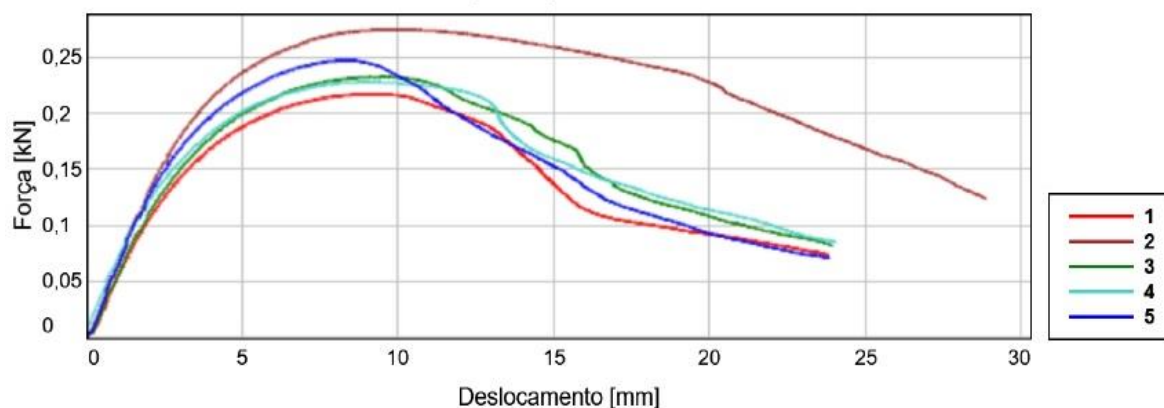
As a result of the tests, it was possible to obtain an average maximum flexural strength of 6.91 MPa, in which the maximum average applied force was 0.24 kN. The average maximum displacement was 24.892 mm until the moment of rupture. The standard deviation of the maximum applied force is 0.020 kN (Table 4).

Table 4 – Flexion test data

Corpo de Prova	Força Máxima (kN)	Deslocamento Máximo (mm)
1	0,22	23,84
2	0,27	28,85
3	0,23	23,91
4	0,23	24,03
5	0,25	23,83
Média	0,240	24,892

Figure 18 shows the performance of the specimens during the test, so it is possible to visualize the Force x Displacement performance of the 5 samples used.

Figure 18 – Force x Flexion Displacement Chart



All specimens broke only at the bottom, where they were undergoing traction. In the upper part, in which the specimens were subjected to compression, there was no breakage (Figure 19), which confirms the results already obtained, the material has greater resistance to compression.

Figure 19 – Broken specimen after bending test



4.2.4 Izod Impact Resistance Test

Table 5 presents the results provided by Professor Éder of resistance to impact, in which it was performed with four specimens, but the first was discarded due to the very high difference in value to the others.

Table 5 – Impact resistance data

Corpo de Prova	Energia Absorvida (kJ/m)
1	382,004
2	1118,865
3	1160,467
4	1494,180

The average energy absorbed in kJ/m for the last three specimens is 1257.837. Likewise, the standard deviation is 205.733 kJ/m.

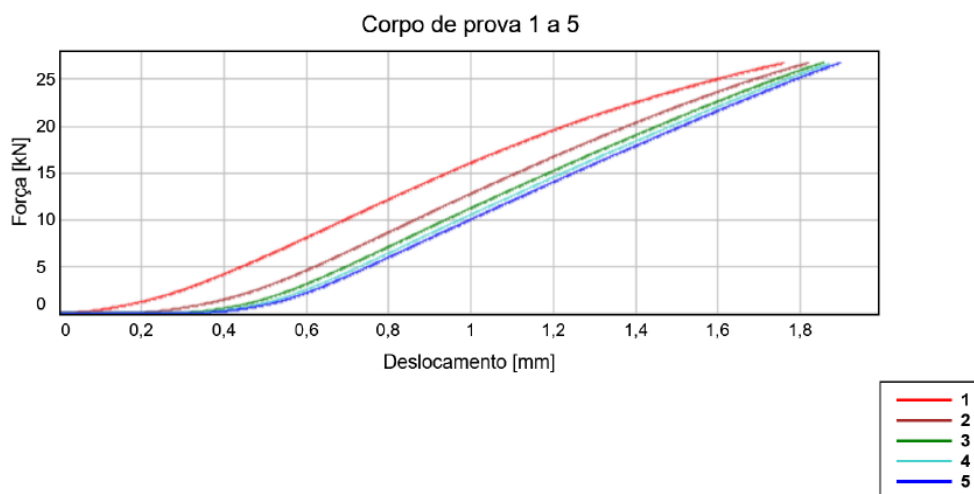
As shown in Table 5, the material performed very well in energy absorption, that is, high toughness. However, as noted, the standard deviation obtained a very discrepant result, which shows that the dispersion of the material in the matrix base is high.

4.3 Characteristic tests for manhole covers

4.3.1 Residual Arrow Test

As a result of the test, successive forces of 2/3 of the control loads of class D400 were applied, according to NBR 10160. After removing the forces and measuring the arrow, displacements of 0.10 mm were obtained in the geometric center of the part, which is within the maximum allowed displacement of all lids classes, up to D400 (Table 6). Figure 20 shows that while 2/3 of the force of classes A15 and B125, 1 kN, and 8.33 kN are being applied respectively, the part has not yet undergone any type of permanent displacement.

Figure 20 – Residual arrow test graph



Based on Table 6, it can be seen that all control loads are within the maximum required by rule, that is, they support their respective residual arrow.

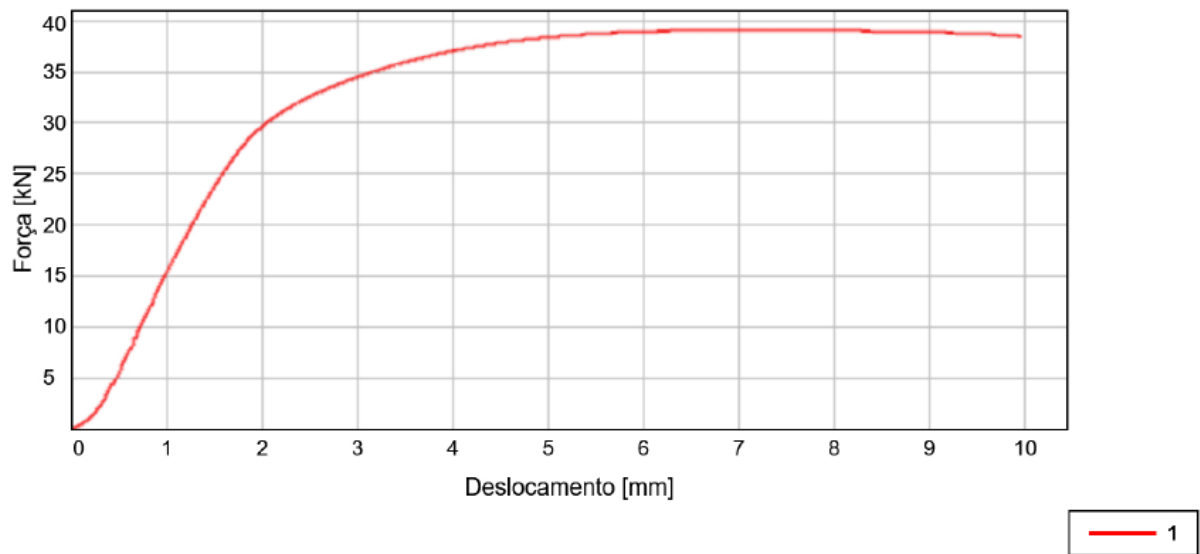
Table 6 – Residual arrows allowed by class

Classe de Tampão	Flecha Residual Admissível (mm)
A 15	0,01
B 125	0,01
C 250	0,20
D 400	0,20

4.3.2 Control Load Test

As a result of the test, when reaching the value of 38.39 kN, the machine automatically stopped the test because there was deformation in the body (Figure 21).

Figure 21 – Control load test curve graph



According to NBR 10160, the specimen cannot undergo any permanent deformation with the application of the control load. As the graph shows, there was deformation with the applied force of 38.39 kN, the same deformation became permanent in the part, as shown in Figure 22.

Figure 22 – Deformed specimen



5. DATA ANALYSIS

5.1 Material characterization

As the results of the chemical and mechanical characterization tests, there was a divergence in the comparison with the specifications provided by the manufacturer.

Table 7 – Summary of material characterization tests

Norma	Ensaio	Dado fabricante	Resultado ensaio
ASTM - D638	Tração	19,49 MPa	8,105 MPa
ASTM - D695	Compressão	39,11 MPa	44,22 MPa
ASTM - D790	Flexão	0,11 kN	0,24 kN
ASTM - D256	Impacto de izod	1970,4 kJ/m ²	1257,9 kJ/m
ASTM - E2550	TGA	419,66° C	441,61° C

According to the results presented in Table 7, the material in question did not reach the tensile and impact resistance specified by the manufacturer. In turn, the results of the compression and bending tests reached values greater than that guaranteed in its specifications.

5.2 Material applicability

As the results of the characteristic tests for manhole covers, the following comparison was obtained.

Table 8 – Summary of material applicability tests

Norma	Ensaio	Classe D400	Classe A15	Classe B125	Resultado ensaio
NBR 10160	Flecha residual	0,20 mm	0,01 mm	0,01 mm	0,10 mm
NBR 10160	Controle de Carga	40 kN	1,5 kN	12,5 kN	38,39 kN

According to the results presented in Table 8, it can be analyzed that the material tested does not meet the specifications for the use standard as a class D400 cover, but it proportionally meets classes A15 and B125. This can be attributed to the concentration of inorganic load indicated in the TGA test since it decreases the mechanical resistance of the material and does not guarantee the passage of heavy vehicles frequently on its surface.

6. CONCLUSION

Given the studies aiming at a new destination for the material, it was found that the replacement of the lids by the studied plastic wood meets the requirements of the standard only for two classes, A 15 and B 125. Class A 15, according to NBR 10160, is used in areas of restricted pedestrian circulation, without vehicle traffic, while the B 125 covers the devices recommended for use on sidewalks or places for pedestrian circulation and passenger car parking areas.

There is a lack of standards for plastic wood in Brazil, which makes it difficult to study the material as it needs to be analyzed based on standards of different elements. The characterization tests performed were all following international standards, while the characteristic ones, according to ABNT for caps and grids in cast iron.

Characterization tests showed that the composite is not a cohesive material, does not have a good dispersion, presents bubbles and inorganic fillers, which end up reducing its mechanical properties, but still has a certain resistance to be applied in areas with few mechanical stresses and frequency diminutive of them, adopting a robust thickness of 30 cm, in addition to being a material that proved to be excellent at absorbing energy, that is, it resists impact well.

Plastic wood has several advantages over natural wood, in addition to being a sustainable product, it can be applied to simpler manhole covers and grilles, replacing the cast iron that can be applied for so many other purposes and thus, giving a destination to plastic waste. However, it is worth emphasizing that the monitoring of the development of plastic wood for such purposes must be done, in order to guarantee the control of the properties of the polymer, considering that it will be subjected to variations in temperature and efforts.

References

ALMEIDA, Aquiles Bezerra. **Plastic Wood: technical and economic feasibility study from solid waste** – Thesis degree UFRS, Porto Alegre, 2013.

Ecocasa; **PLASTIC AND ECOLOGICAL WOOD BRINGS INNOVATION TO ENVIRONMENTS**. 2011. Available in: <<https://www.ecocasa.com.br/madeira-plastica-e-ecologica-traz-inovacao-aos-ambientes>>. Access on 22 Jan. 2019.

ECOWOOD. **Plastic Wood Composition** [personal message]. Received message by <fsoaresmarin@hotmail.com> on 07 Mar. 2019.

ESPÍNDOLA, Letícia Christmann. **Recycling of mixed post-consumer plastics not reused by the sorting centers in Porto Alegre**. 2004. 139 f. Thesis (Master's degree) – Chemical Engineering Course, Universidade Federal do Rio Grande do Sul, Porto Alegre, 2004

FIORELLI, Juliano. **Theoretical and experimental study of glued laminated wood beams reinforced with fiberglass**. 2005. 108 f. Thesis (Doctorate) – Materials Science and Engineering Course, Universidade de São Paulo, São Carlos, 2005.

GUAMÁ, C. M. F. F *et al.* **Plastic Waste – From its production to plastic wood**. In: National Meeting of Production Engineering. The integration of chains into the approach of sustainable manufacturing. October 13th to 16th. 2008. Rio de Janeiro. RJ.

GUIMARÃES, C. *et al.* **Biosynthetic / Plastic / Sustainable Wood**. Exact and technological sciences, Aracaju, v. 4, n. 3, p. 21–28, April 2018, periodicos.set.edu.br.

GUIMARÃES, Luiz Felipe Cerceau; **Evaluation of the economic technical aspects in the production of plastic wood using recycle materials**. Dissertation (Post Graduation in Chemical Engineering) –Universidade Federal de Minas Gerais. Belo Horizonte, MG, 2013

INBRASIL; **Catálogo**. 2018. Available in <<http://www.inbrasil.ind.br/>>. Access on 16 Sep. 2018.

MESQUITA, Ricardo Gabriel de Almeida. **Inclusion of Lignocellulosic Materials in the Production of Plastic Composites**. 2013. 104 f. Dissertation (Master) – Science and Technology Course in Wood, Universidade Federal de Lavras, Lavras, 2013. Available in:

<http://repositorio.ufla.br/bitstream/1/757/1/DISSERTACAO_Inclus%C3%A3o%20de%20materiais%20lignocelul%C3%B3sicos%20na%20produ%C3%A7%C3%A3o....pdf>. Access on 15 Oct. 2018.

MOTTA, Débora. **The miracle of recycling plastic in wood**. 2008. Available in: <<http://www.faperj.br/?id=1280.2.3>>. Access on 22 Jan. 2019.

Sustainable world; **The heated market for plastic wood**. 12 may 2010. Available in: <<https://mundosustentavel.com.br/cidades-e-solucoes/o-mercado-aquecido-da-madeira-plastica/>>. Access on 20 Dec. 2018.

NAZÁRIO, Gabriel F. et al. PLASTIC WOOD: A CONCEPTUAL REVIEW. **Engineering in Action Unioledo**, Araçatuba, v. 1, n. 1, p.54-71, Dec. 2016.

O GLOBO ONLINE (Rio de Janeiro). Engineering Institute. **Wood is produced from plastic bags by researchers at UFRJ**. 2008. Available in: <<https://www.institutodeengenharia.org.br/site/2008/06/13/madeira-e-produzida-a-partir-de-sacos-plasticos-por-pesquisadores-da-ufrrj/>>. Access on 04 Feb. 2019.

OHARA, W. S. **Study of the Mechanical Properties of Plastic Wood**. 2011. 54f. Graduation Work (Graduation in Mechanical Engineering) – Faculdade de Engenharia do Campus Guaratinguetá, Universidade Estadual Paulista, Guaratinguetá, 2011.

OLIVEIRA, Evelyn Martins Reale de; OLIVEIRA, Emilly Martins Reale de; COSTA, Raissa Andrade. **Plastic Wood**. 2013. Technical Dossier - Instituto Euvaldo Lodi – IEL, Bahia.

PAULA, Roberta Manfron de; COSTA, Daiane Leal. **Plastic Wood: combining technology and sustainability**. In: Encontro Latino Americano de Pós-Graduação – Universidade do Vale do Paraíba, 8, 2008, São José dos Campos – SP.

PINTO, Mônica. **EXCLUSIVE: Plastic wood has virtually all natural applications – and advantages**. Ambientebrasil. Rio de Janeiro, p. 1-1. 19 Set. 2007. Available

in: <<http://noticias.ambientebrasil.com.br/exclusivas/2007/09/19/33587-exclusivo-madeira-plastica-tem-praticamente-todas-as-aplicacoes-da-natural-e-vantagens.html>>. Access on 22 Jan. 2019.

PINTO, Tarcísio de Paula. Ministry of the Environment. **Elements for the organization of the selective collection and design of the sorting sheds**. Brasil: Ministério das Cidades, MMA - Ministério do Meio Ambiente, 2009. Chap. 3, p. 3.

SILVA, Alex Junio *et al.* **Comparative characteristics of plastic wood with conventional wood**. Vozes dos Vales: Publicações Acadêmicas, Minas Gerais, v. 5, n. 10, p. 01-20, Oct. 2016.

POLICOG. **Manhole Cover and Grid Presentation** [personal message]. Received message by <fsoaresmarin@hotmail.com> in 17 Sep. 2018.

REWOOD. **Plastic Wood Report** [personal message]. Received Message by <fsoaresmarin@hotmail.com> in 17 Sep. 2018.

SALLES, Ana Cláudia Nioac de Salles Programa de Pós-graduação em Planejamento Energético, COPPE. **GREENHOUSE GAS EMISSIONS FROM NATURAL WOOD AND PLASTIC WOOD RAILWAY DORMENTES IN BRAZIL AND GERMANY BASED ON THEIR LIFE CYCLES**. Rio de Janeiro: Universidade Federal do Rio de Janeiro, 2009. p. 15.

STARDECK. **Plastic Wood Technical Report**. [personal message]. Received message by <fsoaresmarin@hotmail.com> in 18 Sep. 2018.

SPINACÉ, Márcia Aparecida S.; DE PAOLI, Marco Aurélio. **Polymer Recycling Technology**. Universidade Estadual de Campinas, Campinas, Química Nova, v. 28, n. 1, p. 65-72, 2005.