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ORIGINAL ARTICLE

# Mechanical and thermal properties of polystyrene and medium density fiberboard composites

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## Abstract

Virgin polystyrene (PS) composites were reinforced with medium density fiberboard (MDF) residue, considering the influence of fiber content. The composites were evaluated for their morphology, identification of functional groups and thermal behavior. Mechanical tests and a degradation study under ultraviolet radiation (UV) were also performed. The results showed that the best properties were obtained for composites with 4% by mass of MDF waste. The addition of residue was found to increase thermal stability of polystyrene compared to its pure form. The morphology of the composites showed homogeneity of the material. In the degradation tests under ultraviolet (UV) radiation, it was found that the presence of MDF residue slows down the matrix degradation process when evaluated by means of tensile strength. Polystyrene composites reinforced with MDF residues showed good mechanical properties and can be applied in the development of materials that do not need a good appearance.

**Keywords:** *waste valuation, pollution, sustainability.*

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## 1. Introduction

The amount of solid waste that has been generated by humanity in recent years raises attention to the problem associated with its disposal, challenging researchers and companies to seek effective solutions to the issue, combined with social awareness[1]. In this sense, polystyrene (PS) is one of the general-purpose plastics with a wide variety of applications due to its good mechanical properties, anti-corrosion capacity and processing performance[2]. However, it generates a lot of waste, as it is used in low-cost articles, disposable parts, such as cups and plates, transparent packaging and housewares, with very short use time. Every year, 13 million tons of PS are produced worldwide[3]. One of the ways to reuse these residues is incineration, but this contributes to the emission of greenhouse gases such as NOx, SOx, COx, which cause climate change and release carcinogenic compounds[4].

Another widely produced waste comes from medium density wood panels (MDF), which are made up of lignocellulosic fibers and synthetic adhesive, joined under high heat and pressure[5,6]. The main application of MDF is in the furniture industry, due to its easy processing and low cost. The global production of MDF together with that of high density panels (HDF) reached 100 million $m^3$ in 2016[7], however, currently, no method is commercially applied to recycle MDF waste and thus it is burned or landfilled[8] after service life.

In the literature there are bit studies about recycle or apply MDF waste. It´s an alternative has been using it as a source of energy in furnaces, but it is still a small percentage in relation to production. The use of these MDF residues as fillers in polymeric matrices has been studied by several researchers with satisfactory results in the production of composites. Hillig et al.[9] characterized composites made of virgin high density polyethylene (v-HDPE) and different types of sawdust from furniture industry, including MDF waste, observing that the inclusion MDF sawdust provided composites with greater resistance to flexion and impact than those manufactured with other types of waste. Gomes et al.[10] analysed the feasibility of using waste from the manufacture of MDF panels as reinforcement in orthophthalic polyester resin, for the development of materials for industrial application. The results pointed out a decrease in mechanical properties for composites as a function of addition of residue. Souza et al.[11] carried out studies on MDF powder waste in order to identify the best method to recover it. For this, they carried out an environmental diagnosis of a small furniture factory and proceeded with the characterization of MDF waste in the form of powder. The results were similar to other reinforcement loads applied in polymeric matrices. Some limitations found for the application of

this residue were the hygroscopicity and the difference in density between the residue and the polymeric matrix. This can be mitigated with previous heat treatment and the use of a coupling agent, respectively.

In general many polymers exhibit some disadvantageous intrinsic properties, such as fragility and flammability[12,13]. In this sense, studies have been carried out to improve its performance of polymers, with materials being added as reinforcement[7]. Possible reinforcement could be wood waste discarded by the furniture industries (included MDF), transforming them into new products[14]. These products could be used as engineering material, or as a new product that can be sold in the furniture industry itself, resulting in environmental and financial benefits.

The aim of this study is to evaluate the mechanical and thermal performance of a polystyrene (PS) polymer composite, associating MDF waste as a reinforcement, and subjected to conditions of accelerated environmental aging by ultraviolet radiation (UV).

## 2. Materials and Methods

### 2.1 Utilized materials

Commercial waste of MDF was donated by N. J. Móveis Sob Medida. Polystirene P.A. grade was purchased from Sigma-Aldrich® and used as received.

### 2.2 Acquisition of composite material

MDF residue was dried in an oven at 120 °C until constant mass. It solid dry material was granulometrically classified using the mesh tyler Bertel, model ASTM 35, operating for 30 min, obtaining particles with size up to 0,500 mm. The PS-MDF composites were prepared by mix of PS and MDF on the proportion described in Table 1. This mix was loaded in an extrusor machine AX PLASTICOS, model LAB-16. Heating zone were programmed to 160, 175 and 200 °C respectively, operating at velocity of 45 rpm. The extruded material was transferred to the AX Plasticos injector, model LHS 150-80, with the engine head temperature in operation, 220 ºC and 20 ºC for the mold.

### 2.3 Fourier Transformed Infrared (FTIR) analysis

The body test was characterized by Fourier transformed infrared (FTIR). Sample spectra were obtained in spectrophotometer Perkin Elmer, model Frontier, working in the ATR mode. Spectra were recorded in the range of 400-4000 $cm^{-1}$, resolution 4 $cm^{-1}$ and 64 accumulations.

### 2.4 Thermogravimetry analysis (TGA)

Thermogravimetric analysis (TGA) was carried out using a Perkin Elmer STA-6000 thermoanalyzer at a heating rate of 10 ºC per min, under $N_2$ atmosphere. The TGA analysis was performed in the temperature range of 30–600 ºC.

**Table 1.** Body test composition.

| Steps | Sample Cod | %PS on the matrix | %MDF on the matrix |
|---|---|---|---|
| 1 | PS-M0 | 100 | - |
| | PS-M4 | 96 | 4 |
| | PS-M8 | 92 | 8 |

### 2.5 Tensile strength test

Tensile strength test were performed in triplicate using the Texturometer TA equipment HD Plus, branded Stable Micro Systems, according to ASTM D638-10 and traction speed of 5 mm/min.

### 2.6 Scanning electron microscopy (SEM)

The SEM images were taken from test body in a microscopy FEI, model Quanta 250. The samples were first fractured and sputter coated with a thin layer of gold and then observed at magnification of 1000x. All the SEM images were taken at 23 °C and accelerating voltage was 10.00 kV.

### 2.7 UV-accelerated aging effect

The UV-accelerated aging effect was studied with help of the equipment Bass model "UVV Simulador Acelerado de Intemperis". The procedure was performed according to cycle 6 from ASTM G154-06. The analysis were realized in triplicate, the exposure time to UV light was 12 hours, divided in two parts. First, the sample were exposed at 1,55 $W/m^2$ and wavelength of 340 nm for 8 hours at 60 ºC, and after they were exposed for 4 hours of condensation at 50 ºC. The total exposure time was 2016 hours (12 weeks) divided into two, four, eight and twelve weeks of photo-exposure.

## 3. Results and Discussions

### 3.1 Fourier-transform infrared spectroscopy (FTIR)

Analyses were performed for the MDF powder after drying and uniformity of the particles; for the polymeric matrix and for composites developed using MDF and polystyrene matrix. Figure 1 shows the comparative results of the FTIR analyses.

FTIR spectrum for pure MDF powder shows absorption bands characteristic of the constituents of the material. The 3338 $cm^{-1}$ band, attributed to the O-H stretch, corresponds to the adsorbed moisture for the cellulose and urea-formaldehyde resin (one of the constituents of MDF)[15]. The bands at

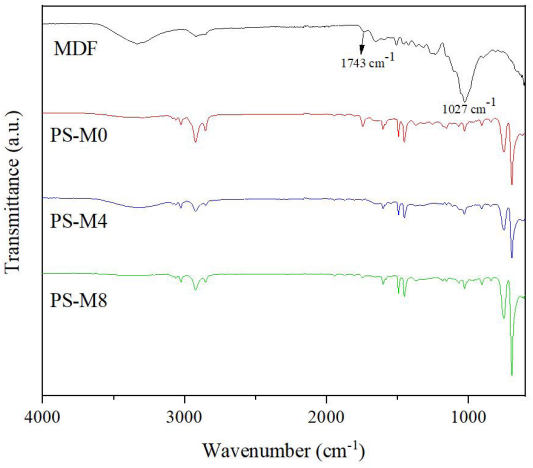


**Figure 1.** FTIR spectra of the MDF residue; virgin PS matrix and PS composites with 4 and 8 wt % MDF.

1246 $cm^{-1}$ and 1035 $cm^{-1}$ correspond to the C-O stretch of the acetyl group, present in lignin and hemicellulose[16].

For the virgin polymer matrix, characteristic absorption bands were also observed and assigned according to the literature[17,18-20]. PS presentes bands at 3025 $cm^{-1}$, associated with the C-H stretch of the aromatic ring, 2920 and 2848 $cm^{-1}$ are related to $CH_2$ strech, asymmetric and symmetrical, respectively. Bands at 1607 and 1490 $cm^{-1}$ are attributed to the C-C stretch of the aromatic ring, 1450 $cm^{-1}$ is attributed to the $CH_2$ stretch of the aromatic ring. The C-H stretch vibrations, also of the aromatic ring, can be observed at 1073, 1020, 750 and 690 $cm^{-1}$. For the polymeric matrix, the band at 1743 $cm^{-1}$ corresponds to the aromatic ring monosubstitution[21]. For the polymeric composites obtained, modification of polymeric matrix was verified at 1027 $cm^{-1}$, related to the C-O and O-H vibrations of the polysaccharides in cellulose[17,18-20]. This indicates a modification of the virgin polymeric matrix when the MDF residue was added, which may cause changes in the mechanical properties of the composites in relation to the pure matrix.

### 3.2 Thermo analyses

Thermo analyses of the samples were performed, monitoring their mass as function of temperature. Figure 2 shows the TGA for MDF, where the first mass loss was shown to occur between 50 and 116 °C, which can be attributed to the loss of moisture present in the residue, a typical hygroscopic characteristic of materials consisting of cellulose[22].

The extrapolated temperature of the beginning of mass loss ($T_{onset}$) for the MDF residue was 284 °C. Khanjanzadeh et al.[23] verified a similar result in their study, showing that the loss of MDF mass starts at 285.4 °C. In addition, it was found that at 231 °C only 5% of the mass is lost and 10% of loss of mass occurs at 268 °C. The second event of mass lost in composites using MDF occurs between 250 and 380 °C and can be associated with the release of volatile matter, which consists of toxic and carcinogenic chemical compounds added to wood and its derivatives, such as formaldehyde, which is harmful to human health and the environment[24]. Above 380 °C there occurs degradation of carbonaceous constituents such as lignin, for example.

The results of the thermogravimetric analyses were compared for virgin polystyrene and for samples with different levels of MDF residue, shown in Figure 3.

For the virgin polymeric matrix, the temperature of the beginning of the degradation was 387 °C. Botan at al. showed that this material started to degrade at temperature around 360 °C[25]. Dominguini et al.[26] showed results where the thermal decomposition of the pure polystyrene started at 380 °C. In our study, we found that the residual mass resulting from the PS burning process is practically zero, and all samples containing MDF presented a single mass loss event, as well as the polystyrene matrix. The results show that the addition of MDF waste slightly increases the temperature at which degradation starts compared to $T_{onset}$ of the pure PS. The percentage of MDF did not influence the degradation temperature of the polymeric composite. As reported by Spinacé et al.[27], phenols present in lignin

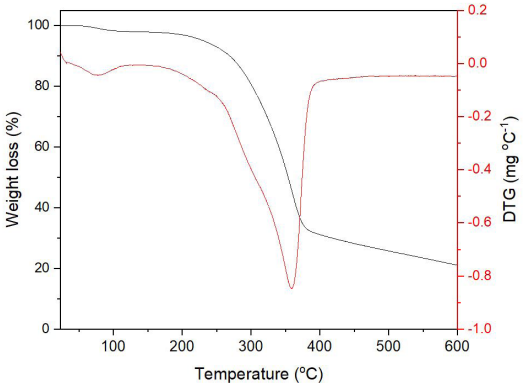


**Figure 2.** TGA and DTG curves of MDF waste.

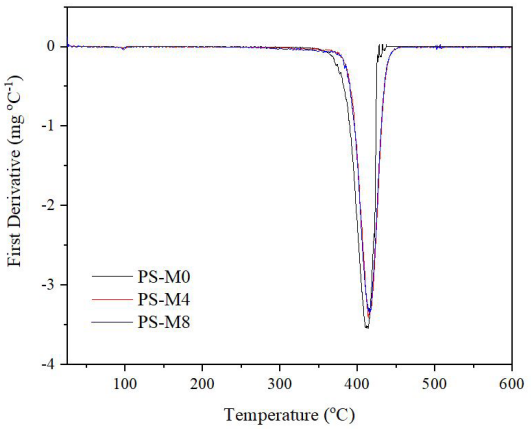


**Figure 3.** DTG curves to MDF composites and polymeric matrix.

may eventually act as scavengers of free radicals, delaying the thermal degradation of the polymer.

### 3.3 Tensile strength test

Tensile strength results, performed in triplicate analyses, for the body test of virgin polystyrene with different levels of MDF residues were compared. For the studied samples, Young's modulus was obtained, as shown in Figure 4. The literature shows that the Young modulus obtained for commercial virgin polystyrene is between 2.28-3.34 GPa[28]. It was observed that the tensile strength of virgin polystyrene in this study showed a reduced value compared to commercial virgin polystyrene, due to the processing to which it was subjected in the extruder.

As observed, composites with a content of 4% suffered lower elongation of the composite and, therefore, have a greater Young's modulus when subjected to tensile tests. For the 8% MDF residue content, Young's modulus remained unchanged compared to virgin polystyrene, around 2.0 GPa. Borsoi et al.[29] have observed that Young's modulus increased compared to pure PS, a result that gets being more pronounced for the 20% cotton fiber using compatibilizing agent. With the increase in the fiber content, the stresses become more evenly distributed, with this, the incorporation of discontinuous fibers in the thermoplastic polymer matrix improves the rigidity

and resistance properties of the obtained composites[30]. In our study, this was not observed, which may be related to inefficient homogenization of samples, with more residue content inside of the extruder. Although incorporating MDF waste does not improve the material's Young's modulus compared to pure PS, it should be taken into account that this method promotes the encapsulation of waste, which is commonly burned and generates gases that are toxic to human health and the environment. It is important to note that the developed composites have properties that make their commercial use feasible, as required by the normative document ANSI A 208.1[31]. According to these standards, the value of Young's modulus should be 2,300 MPa (2.3 GPa),

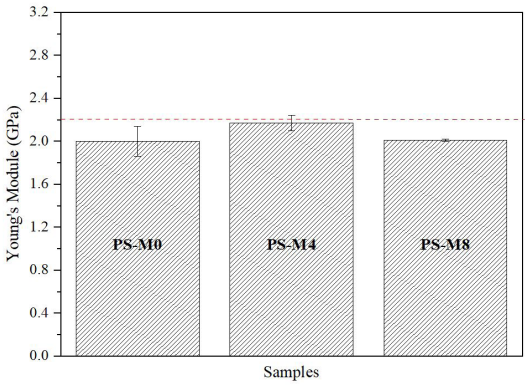


**Figure 4.** Elasticity modules to composite as a function of % MDF.

indicating that the polystyrene composite with 4% MDF residue can be used in making plastic wood.

### *3.4 Evaluation of degradation to accelerated aging in a UV chamber*

The main changes that a polymeric material degraded by UV radiation can acquire are yellowing, changing the surface appearance of the material and reducing its mechanical properties[32]. Thermal properties of pure polystyrene and samples with 4 and 8% by weight of MDF powder subjected to accelerated degradation by UV were analyzed. The results are showed in Figure 5.

The DTG graphs show that all samples presented a single mass loss event. Temperature of degradation onset for pure polystyrene and for the composites did not show significant changes with the aging time. This indicates that photodegradation does not alter the thermal properties of the material, regardless of the MDF content used in the composite.

Figure 6 shows the morphology of the PS, PS-M4 and PS-M8 samples, exposed to accelerated aging in a UV chamber after 90 days, compared to the samples before exposure.

The micrographs were taken from the fractured samples after performed mechanical test, at a magnification of 1000 x. Analyzing the images, it is founded that the samples have a good homogeneity, not was observed the presence of agglomerates of MDF particles (originally in the range of 500 μm). Also, not was found cavity, which can originate

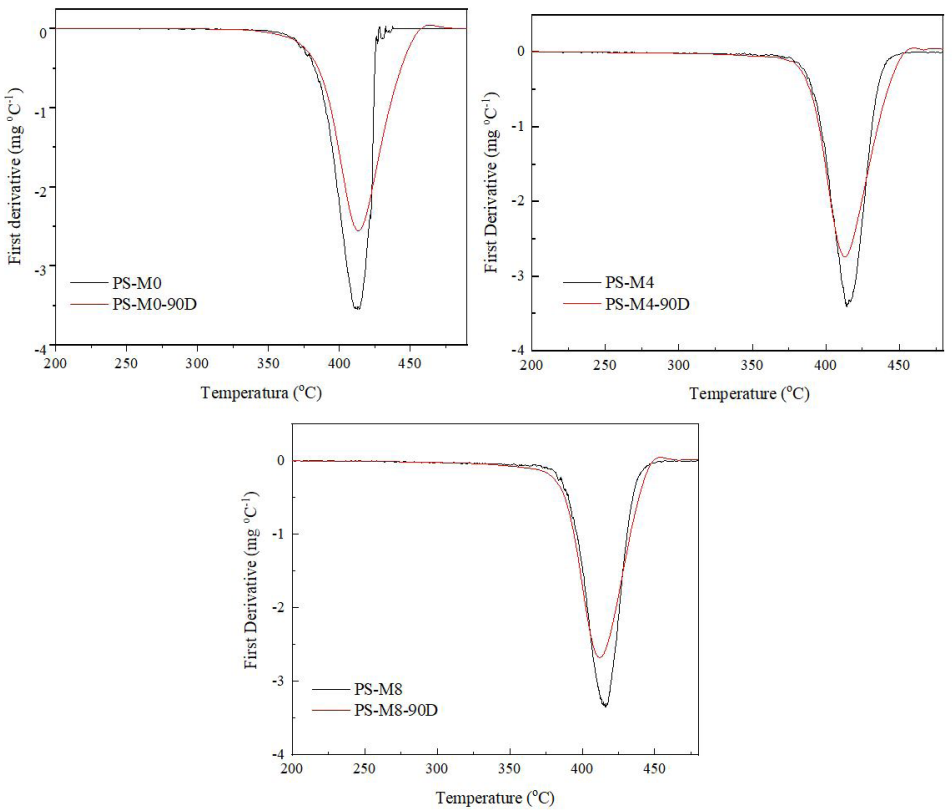


**Figure 5.** DTG curves to pure PS, composite PS-MDF 4% and 8% of MDF, no aging and after 90 days accelerated aging.

when the dispersing material has low adhesion to the matrix, suggesting a good dispersion and adhesion[33] of the MDF powder in polystyrene matrix. It´s a few changes were observed in both pure polystyrene matrix and composite material. After photo-irradiation, greater roughness and cracks were observed in all samples. These cracks were less pronounced for PS-M8 sample, suggesting that adhesion between the components is impaired after UV irradiation[34].

According to Matuana et al.[35], the exposure of the composite to moisture (water in the form of mist) causes swelling in the fiber, causing micro-cracks in the matrix, accelerating oxidation reactions and facilitating the penetration of light. According to Joseph et al.[36], the photooxidation process occurs mainly in the amorphous regions of the polymer due to the greater permeability of oxygen in this region of the material.

Figure 7 shows the sample module before and after exposure to accelerated aging in a UV chamber for up to 2160 hours (90 days).

It was observed a change in Young's modulus for all samples subjected to accelerated aging, under 90 days exposure. This property is very sensitive to structural changes, such as the mass of the polymeric matrix, the density of crosslinking and fiber/matrix interfacial adhesion[37]. Considering the standard deviation related to the measurements, polymeric composites reinforced with MDF powder presented a linear increase in module up to 60 days of exposure, whereas after 90 days decreased, indicating that crosslinking with subsequent splitting of the chains may have occurred. Studies show that this increase in Young's modulus is caused by the photodegradation process, that is, due to the crosslinking reactions that can happen during the composite photodegradation process[37,38]. The reduction of this property is attributed to oxidative reactions that lead to the scission of chains that, together with the formation of superficial cracks and loss of interfac adhesion, cause deterioration in resistance[37,39]. Fernandes et al.[38] studied the photodegradation of high impact polypropylene/polystyrene blends. In the case of high impact polystyrene, the authors observed a small increase in Young's modulus. They observed that Young's modulus is obtained in a very small deformation range (elastic region) and, within this range, both split and crosslink reactions,

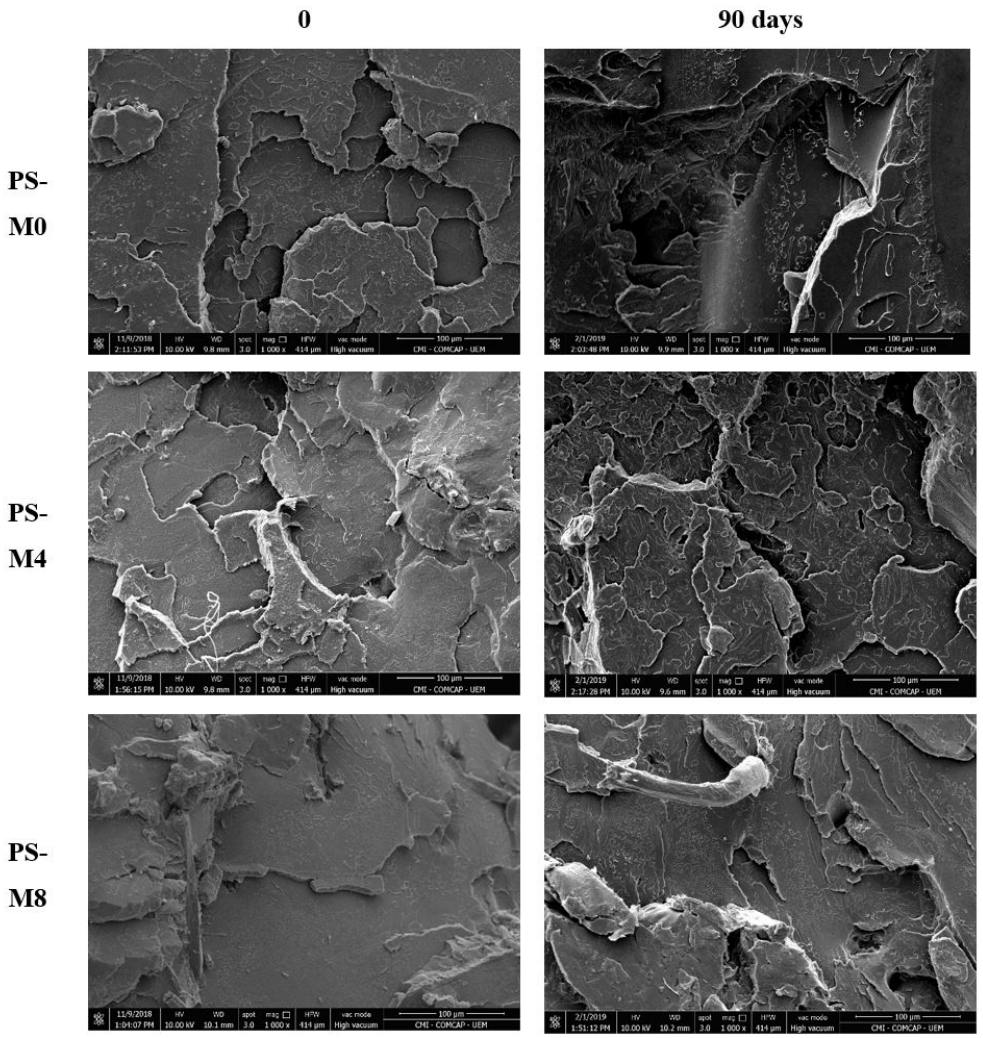


**Figure 6.** Scanning Electron Microscope (SEM) images of a fracture surface of no aging and after 90 days accelerated aging to pure PS, PS-M4 and PS-M8.

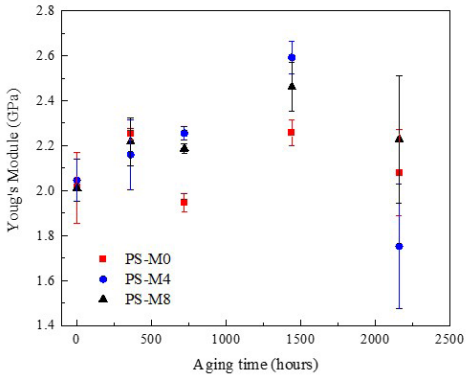


**Figure 7.** Young's module as function of aging time to composite PS-M0, PS-M4 and PS-M8.

even if only at a small degree of intensity, are reflected in this property[38]. This increase in Young's modulus was also observed in the study by Borsoi et al.[40] explaining that this process occurs with some thermoplastics subjected to certain degradation processes.

According to the ASTM G154-06, 1000 h of accelerated aging is equivalent to 1 year of natural exposure to UV. Polystyrene composites with 4% by weight of residue MDF showed values of Young's modulus about 2.3 GPa, after 90 days of exposition, which equates to 2160 h. Considering the normative document, ANSI A 208.1, this material could be used as plastic wood in good mechanical conditions for up to 2 years. Despite the good mechanical conditions, there was a change in the color of the material, becoming whitish over time with accelerated exposure. With such characteristics, the material could be used where good aesthetic conditions would not be necessary, for example, for rural applications.

## 4. Conclusions

According to the results here obtained, we can conclude that the incorporation of MDF waste in the virgin polystyrene to obtain composites, was quite effective, without the use of compatibilizing agents. This may be a technically viable alternative for using these residues in products with higher added value for different destinations, such as for rural applications. It was possible to promote the encapsulation of MDF waste, which is usually disposed of in landfills or burned, releasing toxic gases and contributing to environmental pollution. Future work may be carried out with MDF waste and polystyrene utensils after use, which are discarded. Thus, in addition to reusing MDF, a better destination would be given to post-use PS, which is one of the major generators of environmental pollution today.

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