Research Article

Preparation and Structural Properties of Fibrous Materials-Reinforced Polymer Composites

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Abstract

Effective utilisation of waste paper board (WPB), a solid waste, from the paper industries can be a promising strategy to reduce environmental pollution. In the present study natural polymer composite (NPC) and synthetic polymers composite (SPC) were prepared by incorporating natural and synthetic polymer. Prestin NPC and SPC were compared for their physico-chemical properties. Natural polymers composite have shown better thermal stability compared to synthetic polymer composite. Among the NPC, composites prepared using natural polymer (400mL) exhibited significant mechanical properties such as tensile strength, elongation at break (%), water absorption, desorption, etc in addition to its biodegradation property. Hence, these low cost natural polymer- fibrous material reinforced composites produced using paper industry wastes could be used for multifunctional applications and environmental pollution abatement.

Keywords: Composites, natural polymer, synthetic polymer, mechanical properties

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Introduction

While the increased production and sale of paper products is welcome on the one hand, the generation of enormous amounts of solid and liquid wastes during processing is a problem on the other hand [1]. Other solid wastes generated from the paper industry include agave wastes, pulp wastes, and pulping of agave wastes [2]. Historically, paper waste has been disposed of in landfill sites, but increased restrictions on such disposal have prompted investigations into alternative methods of disposal, and conversion of this waste into useful by-products is a promising strategy.

The literature reports reveal different uses of fibrous materials in fiber-cement composites, filling material, pulp and paper making industry [3]. The cellulose fraction of fibrous materials is used as gypsum-cellulose composites, fiber matrix bonding or as an additive in the construction industry [4, 5]. Senthil et al [6], have reported the preparation of eco-friendly products such as epoxy carbon nanoparticles composites and leather like sheet material from different polymers. Przepiorkowska et al [7], have stated that preparation of composites it consist of chrome shavings leather waste with carboxylated nitrile rubber enhanced its mechanical properties. Preparation of activated carbon from chrome shavings has been reported by Kantarli and Yanik [8]. Fibrous material isolated pulp waste was used as wound dressing material in experimental rats with success results [9].

Lakrafli et al [10], Clearly showed that the reinforcement of chrome shavings and buffing dust leather waste in cement and their use as separation, filling and thermal insulation materials. Composite leather boards prepared using buffing dust and natural rubber latex displayed more excellent mechanical properties [11]. Fibrous materials are synthesized using paper waste show high strength, stiffness, low density and low cost. Natural polymers such as natural rubber latex, rubber tapping, mastication rubber and vulcanisation rubber are used in the preparation of polymer-reinforced composites. These composites, viz., low density, non abrasiveness, combustibility, nontoxicity, low cost, and biodegradability [12]. Natural polymer reinforced composite materials have found commercially in structural applications such as interior items and exterior items [13, 14].

Natural rubber (NR) latex (cis-1, 4-polyisoprene) is an important biosynthesised polymer with an outstanding combination of strength and resilience [15], which exhibits unique chemical and physico-mechanical properties [16]. By using NR as a binder, it is possible to alter the strength, heat resistance, anti-viral properties, biodegradability, oil resistance, gas permeability, wet grip and other related properties to suit mechanical and structural engineering applications [17].

The objective of the present work was to prepare natural polymer composite (NPC) and synthetic polymer composite (SPC) containing waste paper board (WPB) and polymer of natural/synthetic rubber latex, which was used as a binder. The products were chosen for their physico-chemical characteristics using Fourier transform infrared (FTIR), thermo gravimetric analysis (TGA) and scanning electron microscopic (SEM). Mechanical properties such as tensile strength, elongation at break, tearing strength, water absorption and desorption properties were also assessed. This study focusses on the conversion of WPB solid waste into produced value added products parallely decreasing environmental pollution.

Materials and Methods

WPB was collected from neighbourhood places (Chennai, India). Natural rubber latex (NRL) and synthetic rubber latex (SRL) were purchased from Jonson Rubber, (Kerala, India). All chemicals used were of analytical grade and used as such without further purification.

Preparation of natural polymer composite (NPC) and synthetic polymer composites (SPC)

WPB was converted into fibrous material (FM) with help of pulveriser machine. FM (500 g) was soaked in water over night. Later, it was minced using a mincer (*La Minerva C/E 680N*) and ground into a paste using an industrial mixer for 15 min by adding three different concentrations (100, 200, 300 and 400 mL), individually using a natural rubber latex (NRL) and synthetic rubber latex (SRL). The pH was adjusted to 6. Finally 2% of polyethylene glycol was added and mixed thoroughly. The prepared slurry was poured into the vacuum tub having the size 3×2 feet, and the water in the slurry was drained completely. The wet sheet formed was further pressed using hydraulic press to remove additional water. The prepared fiber boards was dried in sunlight for 8 hrs and hot pressed at 40^{o}C for 15 sec at 1000 psi. The composites prepared using FM and NRL were designated as natural polymer composite (NPC), while those prepared with FM and SRL were designated as synthetic polymer composite (SPC).

Characterization of NPC and SPC

Fourier transform infrared (FTIR) measurements were carried out to determine the formation and changes in the functional groups of NPC and SPC. The spectra were measured at a resolution of 4 cm^{-1} in the frequency range of 4000-500 cm^{-1} using Nicolet 360 FTIR Spectrometer. Thermo gravimetric analysis (TGA) was performed using High Resolution 2950 TGA thermo gravimetric analyzer (TA Instrument). Samples weighing 10 and 20 mg were placed in a platinum pan and heated upto a temperature of 800°C at the rate of 5° C /min under nitrogen atmosphere at a flow rate of 50 mL/min. Surface morphology of the samples was visualized by the scanning electron microscope (SEM Model LEICA stereo scan 440).

Mechanical properties

Mechanical properties were assessed using three dumbbell shaped specimens 4 mm wide and 10 mm long. Tensile strength (MPa), elongation at break (%), and tearing strength (N/mm) were measured using Universal testing machine (INSTRON model 1405) at an extension rate of 5 mm/min. Flexing endurance strength was also assessed using Fibre board flexing (TER 74) machine according to STM 129 test method. Water absorption and desorption (%) capacities were also determined.

Statistical analysis

The results were presented as mean ± standard deviation (SD) of three individual experiments (n = 3). ANOVA (Analysis of variance) and Duncan's multiple range analysis were performed to determine the significant differences among the groups. *P* values of $p < 0.05$ were considered as significant.

Results and Discussion

Preparation of NPC and SPC

NPC and SPC prepared using NRL and SRL are shown in (**Figure 1a** and **1b**). Final surface finish was done with protein binders and anionic aqueous pigments (Figure 1c and 1d). They were 3×2 feet in size, with a thickness of 5 mm.

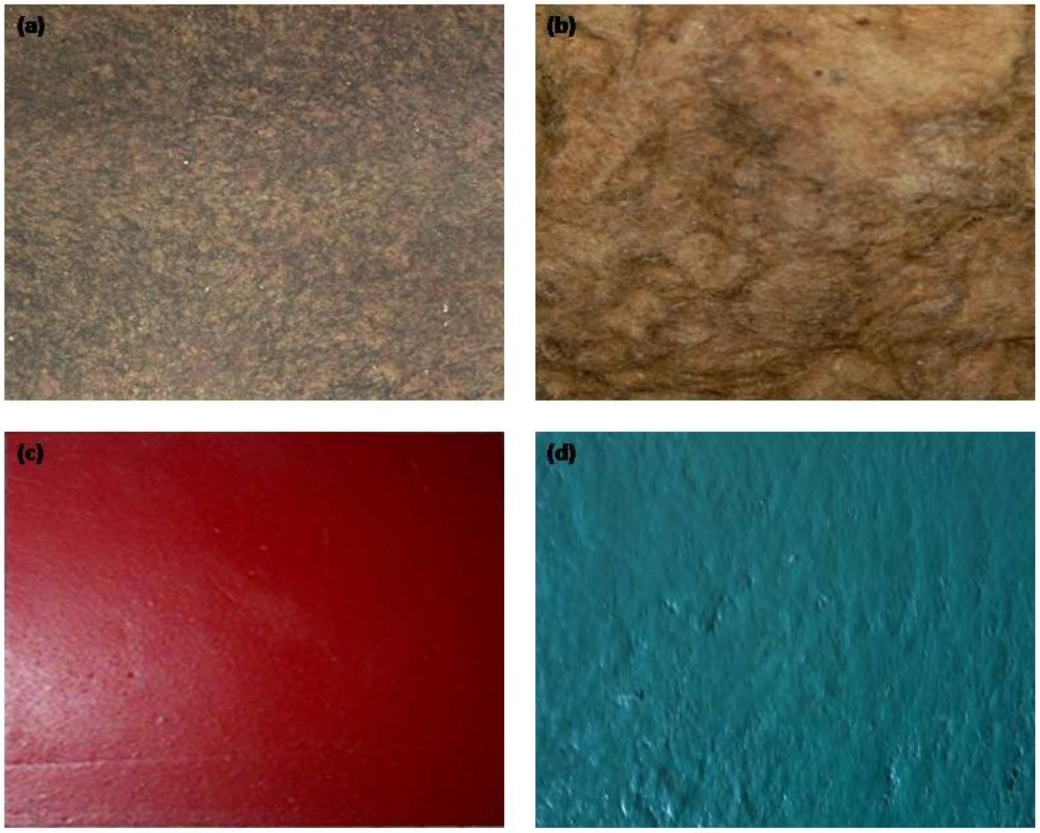

Figure 1 Photographic images of NPC (a) raw board (c) finished board. Photographic images of SPC (b) raw board (d) finished board.

Structural analysis of NPC and SPC

Fourier transform infrared (FTIR) analysis

In FTIR analysis of NPC and SPC, the characteristic band at 1370–1380 cm^{-1} could be attributed to phenolic stretch vibration of O—H and aliphatic C—H deformation in methyl groups of latex. Aromatic C—H in plane bending vibration was detected at 1168$cm^{-1}$and a C—O stretch vibration was observed produced at 1062cm^{-1}. The showed a broad and intense peak at3681cm^{-1}suggesting hydrogen-bonded O—H stretching vibration from the cellulose and lignin structure of the fiber. The peak between 1349 and 1390cm^{-1}, refers to a symmetrical and an asymmetrical deformation of C—H in cellulose and hemicelluloses groups respectively (**Figure 2a** and **2b**).

Thermo gravimetric analysis (TGA)

Thermal stabilities and weight loss changes of NPC and SPC were assessed by TGA (**Figure 3**). In NPC (Figure 3a), a three step weight loss was observed and 3-4 % remained as final residue. Cellulose present in WBP degraded between 300–340 °C; similar results were reported in earlier studies [18]. SPC (Figure 3b) also exhibited a weight loss between 220 °C and 510 °C, with a final residue of 3–4%. The initial weight loss around 100 °C could be attributed to the evaporation of water molecules in the samples. The major weight loss above corresponds to the degradation of cellulose (300–400 °C) and thermally stable lignin (200–500 °C). NRL and SRL; the binder that is present in composites is degraded between 200–550 °C [19]. The final residue was obtained as a result of the loss of hydroxyl groups and depolymerisation of cellulose to hydroglucose units [20].

Scanning Electron Microscopy (SEM) analysis

SEM analysis was done to assess the surface morphology of NPC and SPC (**Figure 4**). In NPC and SPC, the fibrous material was clearly observed and the binding of cellulose fiber by the binder was evident. Well-bound cellulose fiber and polymers were observed in NPC and they also had a smooth surface.

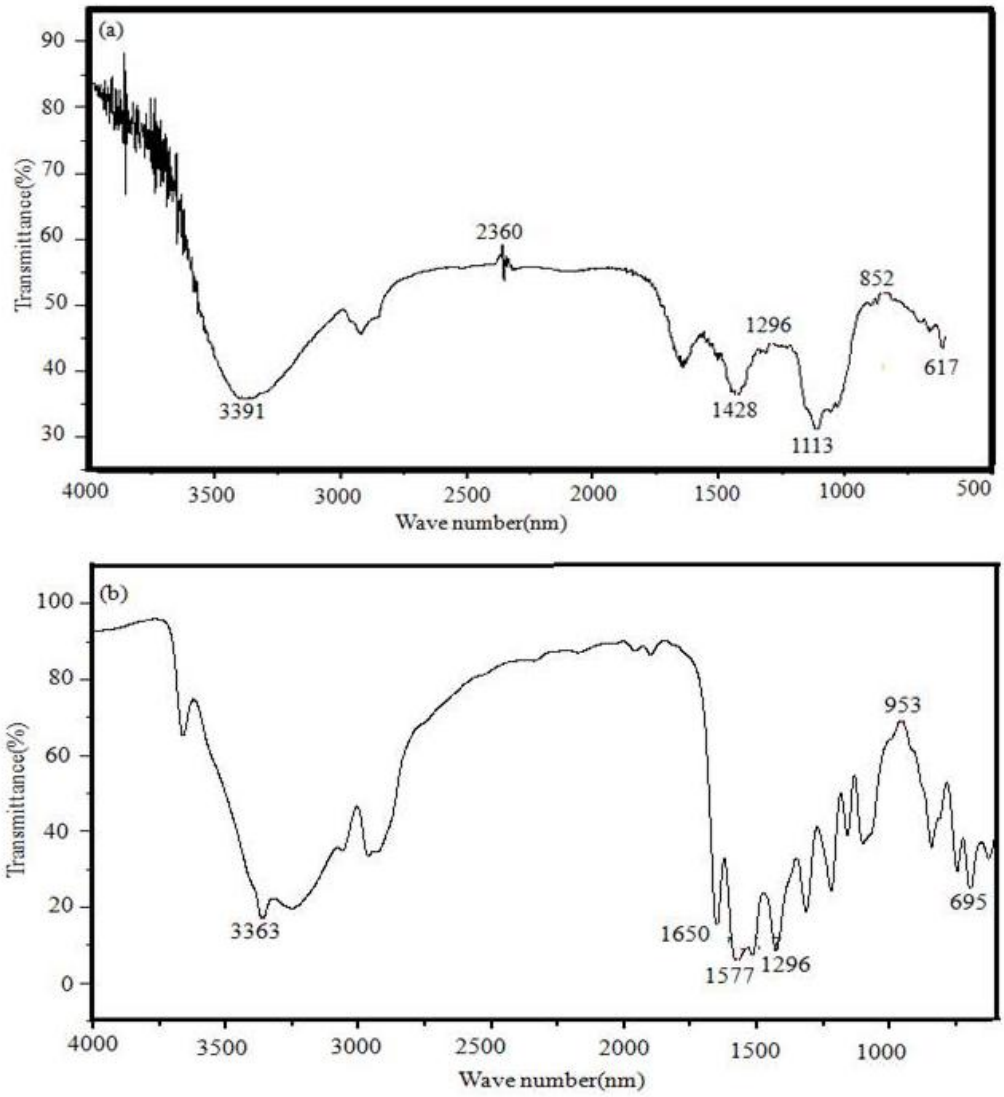

Figure 2 FTIR analysis of (a) NPC (b) SPC

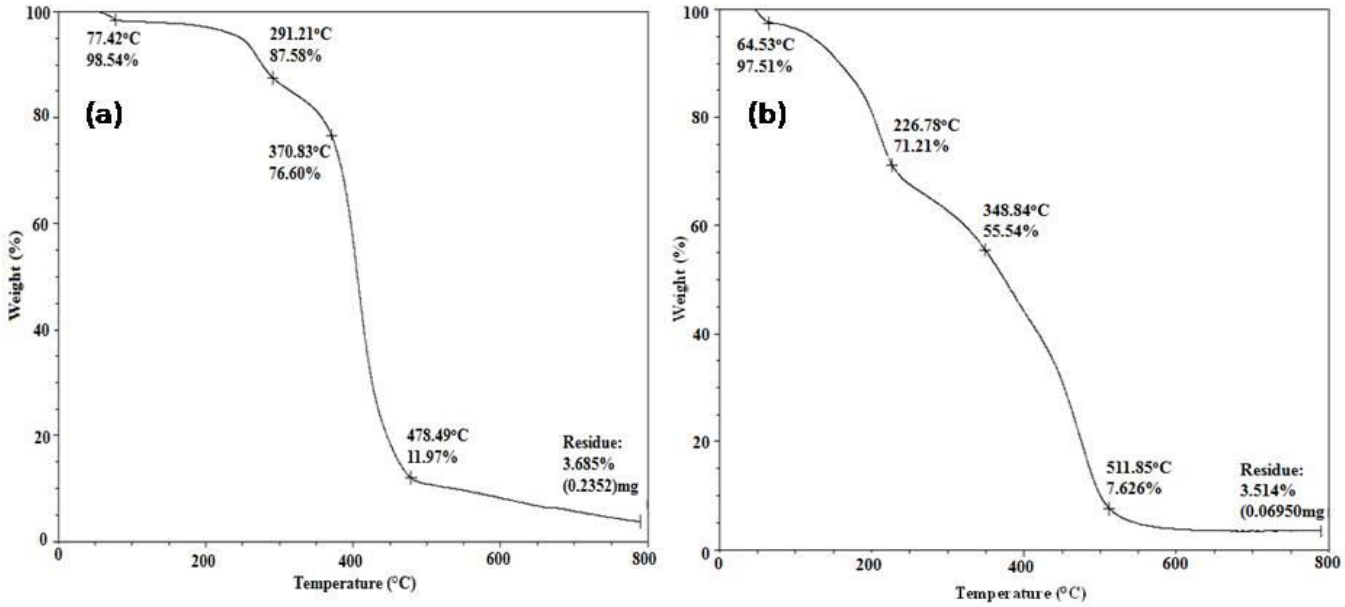

Figure 3 TGA analysis of **(a)** NPC **(b)** SPC

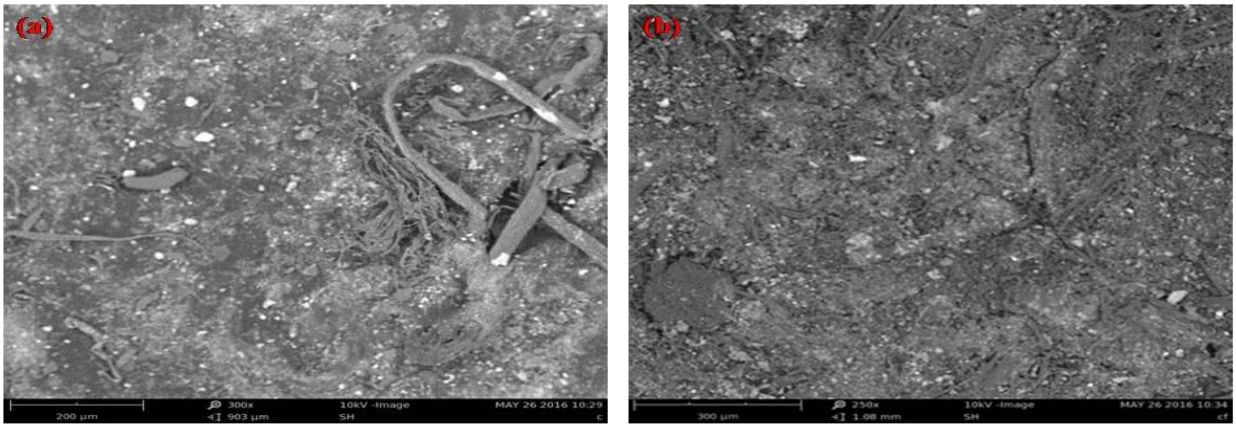

Figure 4 SEM images of (a) NPC (b) SPC

Mechanical properties of NPC and SPC

Fibrous materials reinforced composites are preferred currently owing to their low density and they are a sort of renewable resource, whereas synthetic glass fibers are expensive, have relatively high density, and their production is dependent on non-renewable sources. But, the major limitation in using fibrous material is because of their strength and water absorption property [21]. Hence, these two factors have to be considered in composite production of fibrous material. Also, the end application of the composite decides the role of fibrous material. Fibrous material are basically composite materials designed by nature and consist of a collection of long and thin cells made up of hollow cellulose fibrils held together by a lignin and hemicellulose matrix [22, 23]. The blending of the fibrous material with polymers in the presence of NRL determines the mechanical properties of the NPC, whereas the SBR determines SPC mechanical properties. From **Tables 1**and **2**, it is evident that have augmented the strength of NPC. NPC expressed a significant ($p < 0.05$) increase in tensile strength.

Table 1 Mechanical properties of NPC

S No	Composition (%)	Tensile strength(Mpa)	Elongation at break (%)	Tearing strength (N/mm)	Flexing Index		Thickness
					Along	Across	
NPC (FM:NRL)							
1	500:100 (g:mL)	15.06*±0.35	16.70*±0.2	26.0*±0.75	5.1*±0.1	5.86*±0.4	0.63±0.02
2	500:200 (g:mL)	16.23*±0.25	16.96*±0.49	26.83*±0.45	5.59*±0.31	6.03*±0.3	0.62±0.02
3	500:300 (g:mL)	16.46*±0.45	17.0*±0.2	28.03*±0.96	5.53*±0.24	7.33*±0.20	0.61±0.01
4	500:400 (g:mL)	17.25*±0.25	18.45*±0.33	29.0*±0.50	6.87*±0.28	7.4*±0.60	0.61±0.01

NPC-Natural Polymer Composite, FM–Fibrous Material, NRL– Natural Rubber Latex. The data are presented as mean±SD of three individual experiments. * p<0.05 as compared to SPC, using Duncan's multiple range analysis.

Table 2 Mechanical properties of SPC

S No	Composition (%)	Tensile strength(Mpa)	Elongation at break (%)	Tearing strength (N/mm)	Flexing Index		Thickness
					Along	Across	
SPC (FM:SRL)							
1	500:100 (g:mL)	12.2±0.36	13.3±0.41	22.03±0.2	4.51±0.1	4.26±0.4	0.57±.02
2	500:200 (g:mL)	13.06*±0.40	13.93*±0.66	24.56*±0.25	5.28*±0.2	5.49*±0.39	0.62±0.03
3	500:300 (g:mL)	13.8*±0.2	15.13*±0.2	25.0*±0.36	5.41*±0.19	6.5*±1.3	0.64±0.01
4	500:400 (g:mL)	14*±0.15	15.02*±0.24	25.6*±0.88	6.3±0.52	5.9*±0.87	0.64±0.05

SPC-Synthetic Polymer Composite, FM–Fibrous Material, SRL– Synthetic Rubber Latex. The data are presented as mean±SD of three individual experiments. * p<0.05 as compared to NPC, using Duncan's multiple range analysis.

Cellulose present in wood waste contribute toward increased stiffness of the composites [24]. Sun et al [25], reported that higher lignin content of plant fibers contributes to increase in tensile strength. Since, coir fibre has higher lignin content (59.4%) than sugarcane bagase (13 %) and banana fibre (9 %) [26], the results of this study (wherein NPC composite exhibited higher tensile strength values) are also in accordance with the previous reports [27].

Water absorptionand desorption studies

Hemicelluloses present in plant based material are responsible for biodegradation and moisture absorption [22]. Water absorption and desorption are important aspects of composites, which are intended for use in interior items preparation. A dry surface is preferred for preventing microbial growth. Water absorption and desorption values of indicating no significant differences between NPC and SPC (**Table 3** and **4**). It could be observed from the results that a higher proportion of fibrous materials contributed to better mechanical properties, which is also in accordance with the results of Velmurugan and Manikandan [28].

Table 3 Water absorption and desorption properties of NPC

S.No	Composition (%)	Water Absorption (%)	Water desorption (%)	Thickness (mm)
NPC (FM:NRL)				
1	500:100 (g:mL)	50*±2.0	53.66*±4.7	0.63±0.02
2	500:200 (g:mL)	50*±1.0	54*±3.6	0.62±0.02
3	500:300 (g:mL)	40.33±2.08	67±4.35	0.61±0.01
4	500:400 (g:mL)	41.66±3.51	67.26±3.52	0.61±0.01

Table 4 Water absorption and desorption properties of SPC

S.No	Composition (%)	Water Absorption (%)	Water desorption (%)	Thickness (mm)
SPC (FM:NRL)				
1	500:100 (g:mL)	38.6±1.73	66.21±3.53	0.57±.02
2	500:200 (g:mL)	49.66*±1.52	56.33*±3.51	0.62±0.03
3	500:300(g:mL)	53*±2.0	62.83±1.75	0.64±0.01
4	500:400 (g:mL)	51.46*±2.15	53.66*±4.72	0.64±0.05

Conclusions

An attempt was made in this study to prepare NPC and SPC reinforced with polymers. Out of four different concentration of polymer used, the composites prepared using NRL (400 mL) exhibited better mechanical and other related properties and these composites could be used for roofing, wall partitions, leather goods, components of furniture etc. The current study portrays inexpensive NPC and SPC production from solid waste, thereby reducing pollution.

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