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RECYCLED PLASTIC COMPOSITES IMPREGNATED WITH ORGANOCLAY AS POTENTIAL GEOGRID REINFORCEMENT MATERIAL FOR PAVEMENT APPLICATION

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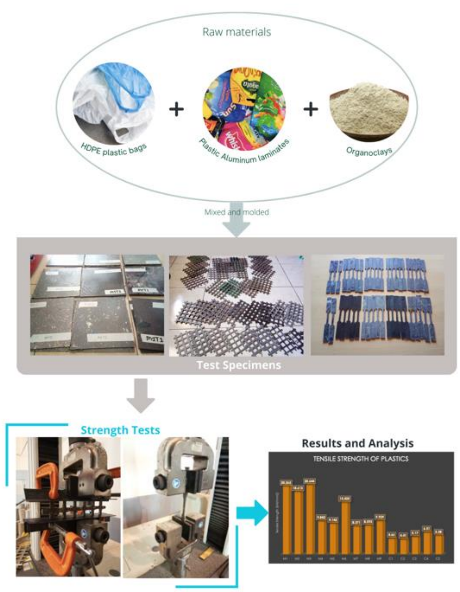
Graphical abstract



Abstract

Geogrid in pavement application is widely used today, as it mainly functions as soil reinforcement or as a separator. Geogrid is made up of polymers which makes it resistant to degradation. There are different kinds of polymers which are widely used today in a familiar term called plastics. For the past years, plastic aluminum laminates (PAL) and high-density polyethylene (HDPE) plastic bags were used as packaging materials or containers. However, the use of these plastics generates a huge amount of waste, consuming a lot of space and damaging the natural state of the earth. This research aims to utilize these wastes to form geogrid, which will be applied in pavement design. The recycled plastics undergo the melting process, with the aid of the two-roll mill and the compression molding. Then apertures are carved into a grid-like structure. A total of nine mixtures of geogrids were produced, each mixture having a different composition of HDPE, PAL, and organoclay. Tensile test for geogrids by Multi-rib Tensile Method (ASTM 6637) and tensile test for plastics (ASTM D638) are followed to test the geogrids. Based on the data obtained, it showed that higher tensile strength is achieved when the amount of HDPE composition in the material increases. In terms of the addition of organoclay, the mixture with 98% HDPE and 2% organoclay produced the highest tensile strength. The product of the study exhibiting the highest strength was classified as either class 2 or class 3 geogrid.

Keywords: Soil reinforcement, recycled plastic, organoclay, geogrid, pavement reinforcement

1.0 INTRODUCTION

Plastic aluminum laminate (PAL) is a form of polymer-matrix composites which are mostly used as packaging for many products. It consists of different sheets of reinforcing materials that are bonded together under heat and pressure with impregnation of thermosetting resins. On the other hand, high-density polyethylene (HDPE) is the densified form of polyethylene, which is the most widely used plastic in the world made from ethylene gas. Recent decades showed an increase in plastic materials being embedded in most of our commodities because of their durability and availability.

The problem with the growing use of plastic is waste disposal. There is a continuous search for ways to reduce plastic waste since it takes a long time before it degrades fully. In 2015, the Philippines produced 39,422.46 tons of waste per day. The waste produced is dominated by biodegradables (52%), recyclables (28%), residuals (18%), and hazardous materials (2%) [1]. Plastic packaging waste, of which plastic laminates and HDPE plastic bags, are considered recyclables.

In engineering, polymers are used to produce geosynthetics. Geosynthetics are fabric-like material formed from polymers. Under geosynthetics are geotextiles, geomembranes, geogrids, geonets, and geocomposites. These materials are used for separation, reinforcement, filtration, drainage, and moisture barrier [2]. Geogrid is a network formed by intersecting elements with apertures greater than 6.35 mm which serves as reinforcement system due to its interlocking with the surrounding soil particles [3]. It is used as soil reinforcement which aids in distributing the stresses evenly and is known to have economic and ecological value as compared to the conventional methods of strengthening soil [4]. The most common compositions of geogrids are polypropylene, polyester, and polyethylene which all have high resistance when it comes to degradation [2].

In pavement engineering application, geogrid has two functions: as reinforcement, and as separator. It reinforces the soil creating a more stable pavement system. Geogrid-reinforced construction achieved higher ultimate bearing resistance through the interlocking mechanism and the confining effect of the geogrid creating a more favorable stress path [4]. It also can separate pavement materials, namely the subgrade and the fill material, which is influenced by the gradation of the materials. Geogrid is used as a mechanical subgrade stabilization, aggregate base reinforcement, and asphalt concrete overlay reinforcement. Numerous research about the strength improvement and cost considerations of geosynthetic-stabilized road construction versus the conventional were undertaken in order to quantify the cost-benefit life cycle ratio of using geosynthetics in the areas of road construction [2, 5, 6]. Considering the concept of sustainability, this research aims to provide alternative geogrid for reinforcing soils as well as eliminating the problem with waste disposal.

Another study recommended a sustainable solution to the waste problem by reusing waste bottles as soil reinforcement that acts similar to commercial geogrid [7]. Plate load test was conducted to compare results for soil that has no reinforcement, soil with conventional soil reinforcement, and soil with the plastic reinforcement. Results of the test showed that the soil with plastic reinforcement was found to have a 15% increase in bearing capacity compared to that of the unreinforced soil. Furthermore, the use of plastic bottle reinforcement saves 60% of cost in comparison to the conventional reinforcement.

In this study, geopolymers are produced with the addition of organoclays. In general, clay has been used as plastic filler before and was found to be effective as reinforcement in polypropylene matrix [8]. Over the years, the idea of modifying clays was developed. One product of modifying clays is the production of organoclays, a new material that acts as an adsorbent of organic contaminants, and a component in the clay-polymer nanocomposites. Studies show that the addition of organoclay into the polymeric matrices improves mechanical, physical and chemical properties [9].

To further analyze the impregnation of organoclay, a study determined the use of PAL impregnated with organoclay as barrier material [10]. Results of the study showed that organoclay impregnation improved the water vapour permeability and thermal insulation property. It concluded that 10% of organoclay impregnation has the least burning rate making it the best thermal insulation material. The 3% impregnation with organoclay was the best barrier material for O_2, N_2, and CO_2, and 1% impregnation was the best barrier material for air.

Similar research showed recycled PAL as material for landfill liner due to its higher physical and mechanical properties, and its chemical resistance to leachate has comparable result with respect to the HDPE liner [11]. This investigation tested recycled PAL samples with 1% impregnation of organoclay and obtained the highest tensile strength reaching up to 445.78 lb/in, a 58% increase in tensile strength compared to a commercial HDPE liner.

This research explores the potential of recycled PAL and HDPE plastic bags as geogrid for pavement application. It also aims to study the effect of clay impregnation in the geogrid, determine the optimum mixture of recycled plastic composites and organoclay in terms of tensile strength, and check the feasibility of recycled plastic laminates as geogrid.

2.0 MATERIALS AND METHODS

The methodological framework of this study is presented in Figure 1. There are five main phases in this research: material preparation, preparation of mixture proportion, molding of the geogrid specimens, specimen testing, and analysis of results. The study will be limited to the addition of organoclay of up to 2% by weight. The effect of the addition of organoclay in the geogrid will only be determined based on the developed tensile strength of the material. Laboratory tests will be performed to determine the potential of the geogrid following ASTM 6637 and ASTM D638. The chemical reaction that will happen as the plastic composites were combined to organoclay as well as the produced new chemical structure of the output will not be studied. To determine the suitability of the geogrid specimen as reinforcement material for pavement design, results will be compared to required geogrid strength based on standards.

Material Preparation

The main materials of the study, which are the recycled HDPE and PAL, were obtained by collecting wastes from residential areas. After obtaining the recycled plastics, the plastic materials were cleaned to remove the dirt and were cut into small pieces. On the other hand, the organoclay procured for this research was bentonite clay. The total amount of the materials obtained for the research is shown in Table 1.

Table 1 Amount of Raw Materials

Raw Material	Mass (g)
HDPE Plastics	7098.3
Plastic aluminum laminate (PAL)	1722.6
Organoclay	89.1

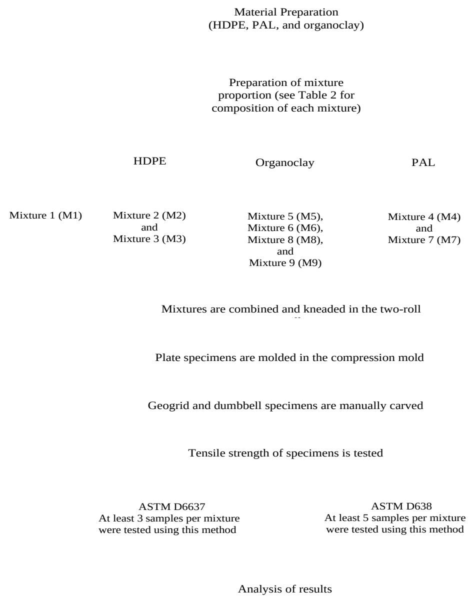


Figure 1 Research Methodology

Preparation of Specimen Mixtures

A total of nine mixtures were used in this study. Table 2 shows the composition of the different geogrid mixtures used in this study. The highest percent of HDPE composition were mixture 1 (M1), mixture 2 (M2), and mixture 3 (M3) having 100, 99, and 98 % HDPE content respectively. These are followed by mixture 4 (M4), mixture 5 (M5), and mixture 6 (M6) having 80% HDPE content. Lastly, the mixtures with the least HDPE content were mixture 7 (M7), mixture 8 (M8), and mixture 9 (M9) having 60% HDPE composition. The addition of organoclay was limited to up to 2% only. This was based on the study that used a combination of organoclay and PAL as material for landfill liner [11]. The PAL served as a filler material to complete the remaining needed mass percent.

Table 2 Mass Composition per Mixture

Polymer Mixture	HDPE Plastic (%)	PAL (%)	Organoclay (%)
M1	100	0	0
M2	99	0	1
M3	98	0	2
M4	80	20	0
M5	80	19	1
M6	80	18	2
M7	60	40	0
M8	60	39	1
M9	60	38	2

Molding of Specimens

After preparing the mixtures, these are brought to the Department of Science and Technology - Industrial Technology Development Institute - Materials Science Division (DOST - ITDI - MSD) laboratory to mold the needed samples of different thickness. The thickness of the geogrid was limited by the equipment in the DOST-MSD laboratory. The thickness of the molded specimen was set to 2mm and 4 mm. The summary of the needed amount of plastic per tile is shown in Table 3.

Table 3 Required mass per tile

Thickness (mm)	Min. amt. of raw materials per tile per mixture (g)
2	150
4	230

The recycled plastics were first placed in the two-roll mill shown in Figure 2. The two-roll mill is used to mix and plasticize uniformly the raw materials to create the polymer mixture. The machine works at 180 degrees Celsius, and it rotates continuously. The plastics stayed in the machine for 5 minutes to make sure that all materials were mixed evenly.

Figure 2 Two-roll mill

After the use of the two-roll mill, the polymer mixture was transferred to the compression molding. The compression molding, as shown in Figure 3, molds the polymer mixture to generate the finished product. The compression molding also operates at 180 degrees Celsius. Different molders were used for different thickness. The specimen passes through the first component of the machine which uses pressure and heat, to facilitate molding.

Figure 3 Compression Molding

Next, the specimen is transferred to the second component, which is the cooling component, to aid in the curing of the material. The output upon molding was an 8-inch by 8-inch tile

(Figure 4). The average measured thickness of the specimens were 3 mm and 4.5 mm.

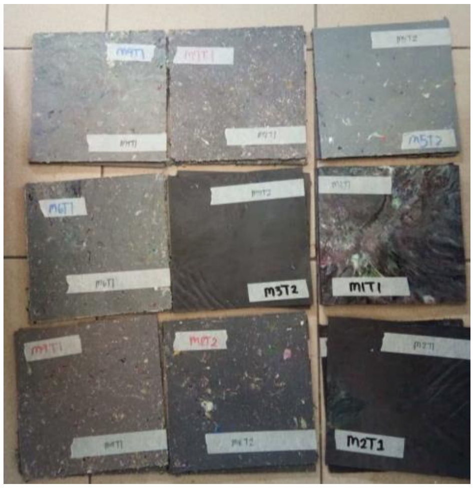


Figure 4 Molded SPECIMEN

The specimens were carved manually in order to achieve the final dumbbell and geogrid design required for testing (Figures 5 and 6). For the geogrid specimen, the design is a biaxial geogrid with a minimum aperture size of 2.5 cm and a rib width of 6 mm.

Figure 5 Actual Dumbbell-shaped specimen used

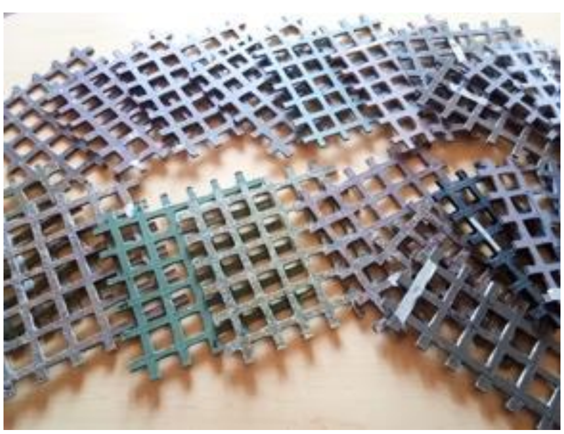


Figure 6 Actual geogrid specimen used with 4 mm thickness

Specimen Testing

Finally, the specimen in each mixture is then subjected to strength tests to determine its tensile strength. For the strength tests, this study conducted and followed ASTM D 6637 [3] and ASTM D 638 [12]. Figure 7 shows the actual test set-up of the specimen by the single and multi-rib method.

Figure 7 Left image: Tensile test of plastic mixtures by the Single-rib Method; Right image: Tensile test of plastic mixtures by the Multi-rib Method

3.0 RESULTS AND DISCUSSION

Polymer Mixtures and their Corresponding Tensile Strength

The results of the test for tensile strength of the plastics following ASTM D 638 are shown in Table 4 and Table 5. The tensile strength shown was the average strength results of the 5 samples per mixture (n = 5).

Table 4 Average tensile strength of plastic specimens

Polymer Mixture	Tensile Strength	
	Average measured value (kN/mm²)	Coefficient of Variation
M1	21.61	0.98
M2	19.13	2.72
M3	19.91	2.11
M4	9.84	6.77
M5	9.14	11.10
M6	15.43	4.02
M7	8.37	3.91
M8	8.59	12.72
M9	9.93	12.26

Table 5 Average elongation and elastic modulus of plastic specimens

Polymer Mixture	Elongation at break		Elastic Modulus	
	Average measured value (%)	Coefficient of Variation	Average measured value (GPa)	Coefficient of Variation
M1	13.42	8.69	0.35	6.98
M2	13.67	10.49	0.31	7.44
M3	13.54	10.09	0.35	4.47
M4	12.81	14.09	0.15	5.12
M5	10.94	14.83	0.14	6.42
M6	9.01	7.85	0.29	2.92
M7	9.84	8.09	0.13	5.22
M8	9.14	10.62	0.15	6.45
M9	7.61	15.62	0.18	8.74

Based on the results obtained, the highest value of the tensile properties of plastic was M1 having 20.61 kN/mm^2. On the other hand, the lowest value obtained was M7 which has a value of 8.37 kN/mm^2. As observed, the high values of tensile strength were achieved when the recycled HDPE plastics were high in composition.

Generally, the tensile strength obtained for PAL and organoclay mixtures have lower values of tensile strength as compared to the mixtures with added recycled HDPE plastics. Based on the results, M1 has the highest tensile strength as compared to M2 and M3. The mixture with 80% HDPE and 2% organoclay (M6) also exhibited the highest strength compared to the other samples with same HDPE content but lower organoclay. The tensile strength obtained was 57% higher as compared to the controlled mixture which is M4. Samples with 60% recycled HDPE plastics component, also showed the same trend with M9 which has a value of tensile strength equal to 9.93 kN/mm^2. This mixture was 19% higher in value as compared to the controlled which is M7. It was also observed that addition of organoclay decreases the tensile strength of some mixtures. This was evident in both M2 and M5 which both have 1% organoclay impregnation. For M2 mixture, the addition of organoclay decreases the strength by 11%, and for M5 the addition of organoclay decreases the strength by 7%.

It was observed that increasing HDPE percent composition shows increasing strength while increasing PAL composition showed a decrease in tensile strength. The same behavior is observed for the elastic modulus and elongation at break.

In terms of its deformation, results show that the ductility of the sample decreases as the amount of HDPE in the mixture decreases. The decrease in ductility is also evident as the amount of organoclay is increased, except, for samples without PAL where it is observed that the addition of organoclay makes the sample slightly more ductile compared to pure HDPE sample.

Furthermore, the addition of organoclay increases the measured elastic moduli of the samples. This means that the samples become more rigid or stiffer as the amount of organoclay is increased.

Sample graph of load versus deformation of samples are shown in figure 8. In this figure, the graph of sample mixtures M1, M2, M4 and M5 were shown. As can be seen, sample mixture M1 has the highest extension or elongation. Comparing this with M2, it can be noticed that due to the addition of organoclay, the extension of the material decreases. Analyzing further, the 2% organoclay addition also resulted in a decrease of extension which was a greater decrease as compared to the 1% organoclay addition. A decrease in extension was also observed in M4. Sample mixture M5 showed a decrease in the extension and thus, has the lowest extension generated.

In general, the mixture with added PAL has minimal elongation. The reason for the difference in rupture was the composition itself of the mixtures. The melting temperature of PAL was higher as compared to HDPE. The machine works at the melting temperature of the HDPE which is 180 degrees Celsius. Thus, the PAL component of the mixture did not melt fully and thus not blended fully with the HDPE plastics. The fact that the mixture did not blend fully causes the composites to break easily. Based on this graph, the ductility of the material was found to decrease as organoclay was added. This was due to the weak bond that was formed by introducing organoclay in the polymer composites.

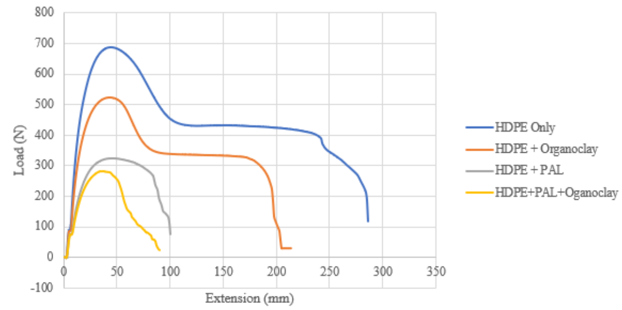


Figure 8 Sample result of tensile strength test

In summary M3, M6, and M9 have the highest tensile strength, in which, all mixtures contain 2% organoclay impregnation. Also, it is observed that the higher the percent composition of recycled HDPE plastics, the samples are stronger, more ductile, and less stiff. The highest tensile strength obtained was observed in M1 which has 21.61 kN/mm^2 tensile strength value. Results also showed that the effect of clay impregnation can either increase or decrease the tensile property of the mixture. Additionally, mixtures with only recycled HDPE elongate more as compared to the mixtures with added organoclay. The addition of PAL also caused a decrease in extension and elastic modulus, thus, the mixture with the least extension was those with HDPE, PAL and organoclay component.

Tensile Strength of the Geogrid

The tensile strength of the geogrids was determined in accordance with ASTM D6637. Table 6 shows the result of the tensile strength test of the geogrid with 3 mm and 4.5 mm thickness.

Table 6 Average Tensile Strength Result for Geogrids

Polymer Mixture	3 mm thick samples		4.5 mm thick samples	
	Average Tensile Strength (kN/mm^2)	Coefficient of Variation	Average Tensile Strength (kN/mm^2)	Coefficient of Variation
M1	8.36	2.77	14.26	8.78
M2	8.01	14.06	13.79	10.08
M3	8.83	6.60	16.15	9.92
M4	7.01	14.83	9.85	11.14
M5	4.64	46.44	9.15	8.42
M6	6.96	14.66	13.77	9.15
M7	5.75	14.16	8.52	3.97
M8	5.93	5.14	10.71	8.31
M9	6.10	24.84	8.73	1.97

The results obtained showed that the geogrid with mixture M3 has the highest value of tensile strength. Mixtures with no PAL content still showed the highest strength. Mixtures with 60% recycled HDPE plastics component, generally showed the lowest observed tensile strengths. The addition of organoclay decreased the strength of the mixture as observed in M2 and M5.

Different behavior was observed for the mixture with 80% and 60% HDPE for the 3 mm and 4.5 mm thickness. The difference might be a result of not fully achieving the composition established due to excess removal in the creation of polymer composites using the compression molding. Higher tensile strength of the geogrids was still achieved from samples with higher composition of recycled HDPE. Also, the addition of the organoclay lead to an increase in tensile strength of the geogrids.

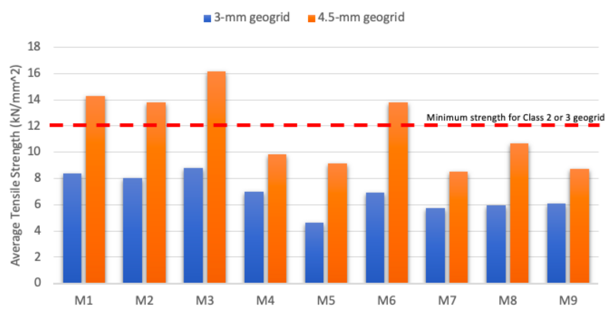


Figure 9 Comparison of obtained average tensile strength result for geogrids to minimum strength requirement [3]

Based on existing literature, the survivability property requirement for stabilization and base reinforcement application under Class 2 and Class 3 geogrids should have at least 12 kN/m, multi-rib tensile strength [3]. Therefore, as shown in figure 9, M1, M2, M3, and M6 (4.5 mm thickness) qualifies for this requirement. This requirement was so far the best to consider since a national guide for geogrids has not been established yet. The value indicated was a conservative value which was very appropriate in public constructions. The usual ultimate tensile strength of geogrid available commercially has strength which ranges from 15- 40 kN/m [2].

Figure 10 shows a sample graph of the load versus deformation of 4.5 mm samples. Similar observation was noticed with the tensile test for plastics, that is, the addition of organoclay decreases the extension of the material (Table 7). Thus, the HDPE and organoclay mixture has lesser extension as compared to the HDPE only mixture. Same trend was observed for the other mixture with added organoclay, thus the 2% organoclay addition also resulted in a decrease of extension which was a greater decrease as compared to the 1% organoclay addition.

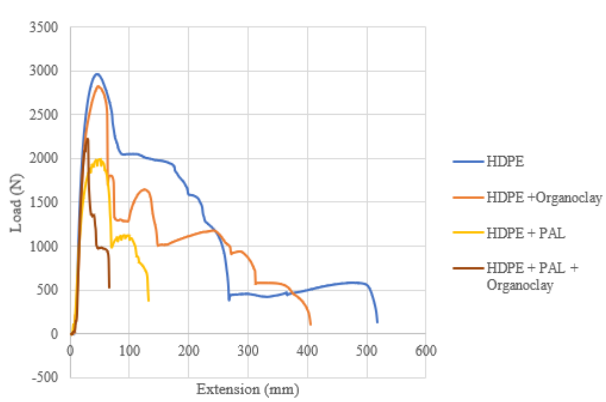


Figure 10 Sample result graph of load versus tensile deformation for 4.5 mm samples

Table 7 Average Tensile Strength and Deformation for 4.5 mm thick Geogrid samples

Polymer Mixture	Average Tensile Strength (kN/mm²)	Elongation at break	
		Average measured value (GPa)	Coefficient of Variation
M1	14.26	4.78	22.86
M2	13.79	3.79	9.32
M3	16.15	3.18	19.32
M4	10.48	3.63	15.33
M5	9.15	3.36	9.16
M6	13.77	3.47	18.23
M7	8.52	2.74	22.40
M8	10.71	2.89	21.20
M9	8.73	2.83	31.27

4.0 CONCLUSION

The study investigated the potential of recycled plastic composites with addition of organoclay as a reinforcement material. After performing necessary test to obtain the tensile property of the material, the researcher concluded the following:

1. Tensile test showed that higher recycled HDPE plastic content showed higher tensile strength of the samples.

2. The study cannot fully prove the exact behavior of the plastic composites due to addition of organoclay. This was due to the limited addition of organoclay which was until maximum of 2% only.

3. The highest tensile strength of geogrid obtained is 16.15 kN/mm² having 98% recycled HDPE and 2% of organoclay with 4.5 mm thickness which qualifies in the requirement as either Class 2 or Class 3 geogrid. Thus, the geogrid samples made from M3 polymer mixture can be used for Class 2 or Class 3 geogrid application such as reinforcement for roadways and pavements.

4. The addition of organoclay and PAL decreases the ductility and rigidity of the polymer composites. The decrease in extension of the polymer composites was due to the addition of PAL.

5. The production of the geogrid contributes to waste reduction and can be potentially sold in the market.

Recommendations

For future studies, the authors recommends determining the effect of addition of organoclay in the polymer composites. Having trials with a wider range of organoclay in terms of mass composition can be performed to check the effect in terms of tensile strength of the geogrid. Using different organoclays can also be studied to know what organoclay can best improve the polymer characteristics. For in depth study, other tests for geogrid aside from tensile strength test can also be performed like tests for junction efficiency, aperture stability, UV degradation Resistance, or chemical damage resistance. Use of other designs, kind of plastic and type of geosynthetic can also be explored in the future.

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