BLOCKS FROM RECYCLED PLASTIC, SAND, AND GRANULAR STONE AS BASE COURSE FOR ROAD CONSTRUCTION

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Abstract

The study entitled, "Blocks from recycled plastic, sand, and granular stone as base course for road construction" aims to provide a new innovative material as a replacement for a typical base course used for road construction with the use of recycled plastic. The main purpose of the study is to determine the capability of the design for commercial use in terms of durability, strength, and economic. Most importantly, to conclude whether it is safe for the environment or not. The design is inspired by the common concrete mixture used for pavements, only. Instead of using cement as a binder, the study used recycled plastic since the study, also aims to help lessen plastic waste in the environment. In this study, a stronger and better base course material is proven to be effective and is recommended for use in road construction. However, the need for further and thorough scientific study might be needed to determine more of its physical and chemical properties as an innovative material.

Keywords: Road Construction, Recycled Plastic, Innovative Material, Base Course.

"Innovation is identified as a very crucial part of the continued growth and development in the construction industry" *(Manley, 8662, Slaughter, 7554)*. Roads are a big part of people's life today, hence the production of more and more types of vehicles that continuously evolve due to the modernization of technology. "And, due to the increased demand for efficiency and innovations, the Philippines has become one of the fastest countries in terms of development" *(www.philstar.com 8671)*. But, in all of this improvement happening in the country, the roads are perceived growing lower and lower in quality and through this research, the researchers believe that it is possible to create a solution to solve the problem in our roads today without spending too much on new materials.

"The Road construction sector is majorly involved in the product innovation" *(Manley, 8664)*. Besides the truth that the people are experiencing these problems with road constructions and it's quality, there is also one growing problem that not only the country but most countries throughout the world faces today. It is the amount of plastic waste that continues to grow in percentage consistently. The Philippines is now producing nearly 300 million tons of plastic each year, half of which is for single-use plastic. And from this, 8 million tons of plastics are dumped into the oceans per year (*plasticoceans.org 8674). "*Based on the report of WWF-Philippines, the country's National Solid waste management and commission, World Bank, a whopping 74 per cent of plastic comes from wastes that has actually been collected" *(wwf.panda.org/Coraltriangle/news 2018)*.

The construction of roads for our transportations takes time to finish and is quite expensive. And, as future Engineers, the researchers must create, preserve and protect our roads for future generations. The researchers have agreed to focus solely on reinforcing concrete mixtures mostly for roads but the research has turned to focus on the base course instead. And with the help of this research, the researchers need not only give out a solution to our road problems but also lessen plastic waste pollution and put these plastics to good use.

A typical road constructions have 4 main layers such as, wear course, base course, subbase, and subgrade. This present research is about a substitute material for the base course. The **base course** in pavements is a layer of material in a concrete pavement. It is located under the surface layer consisting of the **wearing course** and sometimes an extra **binder course**. In short, this particular layer is the one responsible for holding the pavement safe above it. The researchers started discussing the possibility of improving the present condition of pavements by replacing the typical base course material with a stronger material, and since the target is the material below the pavement, the substitute has to have a high impact strength and also compressive strength to support the pavement above it

Review of Related Literature

How did recycling start? *(Time.com/history-origins-recycling) 2016*

"What happened in the 1960s and '70s was not that **recycling** was invented, but that the reasons for it changed. Rather than **recycle** to get the most out of the materials, Americans began to **recycle** to deal with the massive amounts of waste produced during the second half of the 20th century"

Plastic waste in road construction

In an experiment conducted in 2002 by **Prof Rajagopalan Vasudevan,** a professor of Chemistry at Thiagarajar College of Engineering, Madurai, India. He pioneered the technique of making roads out of plastic waste. The idea of innovation comes from his decision to challenge the idea of plastic being banned for most countries and finding a solution for the plastic thrown all over the oceans.

His innovative road idea is composed of mainly plastic wrappers for foods such as chips, biscuits, candies, and more. The plastic waste is shredded to a particular size by the use of a shredding machine. The aggregate mix is heated at 165-degree centigrade and transferred to the mixing chamber, and the bitumen is also heated to 160-degree centigrade to result in good binding. It was noted that the temperature must be kept monitored. The shredded plastic is then added to the aggregate, it gets coated uniformly over the aggregate within 60 seconds. And the plastic-coated aggregate is then mixed with hot bitumen resulting in a mix used for road construction.

Although the facility and machine that they used are not commonly available for the researchers, their study serves as an inspiration for the present study that serves as sources of innovative ideas.

"The advantages of using waste plastics for road construction are many. The process is easy and does not need any new machinery. For every kilo of stone, 50gms of bitumen are used and 1/10th of this is plastic waste; this reduces the amount of bitumen being used. Plastic increases the aggregate impact value and improves the quality of flexible pavements. Wear and tear of the roads has decreased to a large extent," says Prof. Vasudevan, the very proud Plastic man of India.

The said technique was proved to increase the strength of the road, reducing road fatigue. Not to mention, it has an improved resistance to cold weather and rainwater. And, since the amount of plastic that is used to follow the innovative idea, the amount of plastic waste not only in India but also in other parts of the world was reduced.

The college, and the professor, in particular, have been receiving many queries from various countries in

Europe and the Americas for this technology.

This study that is originated by the Plastic man of India is a simple confirmation and proof that plastic and concrete has a good relationship between them. It was very successful for him. As for the idea of this research paper to use plastic waste to be mixed with recycled concrete as a substitute for base course in road construction, the researchers took the "Plastic man's" idea as an inspiration to make the results of the present study as another success in the field of engineering.

Interlocking Technology

Despite the increasing interest in topological interlocking structures made of identical elements, only one type of interlocking brick has been extensively studied so far, with very limited focus on their dynamic behavior. In this paper, a new design of interlocking brick was proposed, which had asymmetrical geometry with four curved side surfaces to be interlocked with adjacent elements. The dynamic mechanical behavior of the new brick was numerically investigated and compared to that of the existing interlocking brick and the monolithic plate. The deformation patterns and the energy absorption capacity of interlocking structures were also studied. The results showed that the newly designed interlocking brick had intermediate contact forces and much more uniform load and stress distribution during the impact. Moreover, its energy absorption capacity was the largest.

In the study conducted by Razaeejavan, Hamed Seifi, Shanqing Xu, and Yi Min Xie, an innovative design of osteomorphic brick is proposed, aiming to achieve better energy absorption capability than existing designs under dynamic loadings. In the new design, all the four sides of the brick/blocks are interlocked and the loads can be transferred through the two additional curved surfaces. With these new arrangements, the mechanical response of the new type of interlocking brick was studied by using finite element modeling. Comparison among the new brick, existing brick, and monolithic plate was also conducted and analyzed. (Razaeejavan, Hamed Seifi, Shanqing Xu, Yi Min Xie, 2016).

This study was so successful that their innovative design is now being used all around the globe. Compared to existing interlocking bricks, their new design was proven to have an evident advantage in both the dynamic mechanical properties and the energy absorption capacity.

Related Study about Wire Mesh as a reinforcement

The field of Engineering and Construction is so familiar with this thing that is called *Ferrocement.* It is also called as Thin-shell Concrete and is a system of reinforced mixture applied over layer of metal wire mesh *(en.wikipedia.org)*. It is used for constructing relatively thin, hard, strong surfaces in many shapes. It has a very wide range of uses like pre-fabricating building components and sculptures.

The researchers used metal wire mesh on the specimen to create a bending stress resisting technology. Since the specimen is made out of plastic, any high amount of bending force applied to the specimen might cause deformation and reinforcing it with metal wire mesh is the solution to enhance the bending strength of the specimen.

Theoretical Framework

This research is about the production of a new base course material to be used in road constructions that uses sand and dissolved plastic waste that formed the product.

The said blocks are made out of dissolved plastic, mixed with fine sand and granular stones, and intended to be used as a base course material. It is through testing that this product may be determined to be stronger and have a longer life span.

A typical road construction consists of 4 major layers. See figure 1 below.

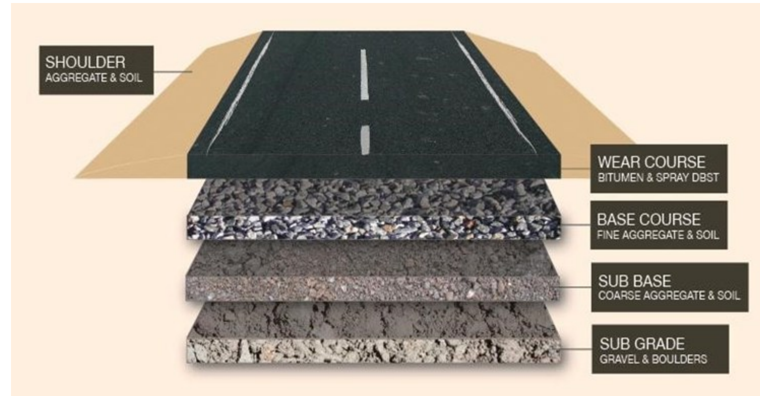


Figure 1. Layers of road

Conceptual Framework

INPUT		PROCESS		OUTPUT
MATERIALS TO BE USED: • Polystyrene (PS) • Wire Mesh • Acrylic Thinner • Sand • Granular Stone • Related Literature and Studies	⇨	PROCEDURE: (Based on ASTM or American Society for Testing and Materials) ASTM C39/ASTM C39M (AASHTO t22), standard for concrete, dried or soaked at the time of loading, ASTM C293 (AASHTO t177) for center-point loading Exposure to Rainwater Contact-Exposure with Soil	⇨	Innovated Recycled Plastic blocks to be used as BASE COURSE in Roads Construction

Figure 2. Conceptual Framework

Statement of the problem

1. How will waste plastic, sand, and granular stones be used for road construction?
2. What are the mechanical properties of the blocks made of 7 parts Styrofoam/Polystyrene plastic, 1 part Acrylic Thinner, 1/2 part Granular Stone and 1/2 part Sand with wire mesh as reinforcement?
3. How to recycle waste plastic without the risk of releasing toxic fumes?

Objectives

This research aims to:

1. To recycle waste plastic mixed with sand to produce another material with a specially designed interlocking technology for road construction.
2. To determine the mechanical properties of the blocks made of 7 parts Styrofoam/Polystyrene plastic, 1 part Acrylic Thinner, ½ part Granular Stone. ½ part Sand with wire mesh as reinforcement?
3. To determine the process of dissolving waste plastics with no toxic fumes released in the environment.

Scope and limitations

It is important to note that the research mainly focuses on the Base Course of provincial/Rural roads only. This limitation to provincial/Rural roads is due to the lack of data needed to account for other kinds of roads in the country such as highways or over/underpasses. Official budget financing of roads are not to be considered because the research is limited only to the amount that will be used by the researchers on the main specimen and not the road construction itself. And to maintain a consistent result, the expected results are to be based and compared on the standard materials used in road constructions. Data of the

materials are derived based on **AASHTO** (American Association of State Highway and Transportation Officials), **ASTM** (American Society for Testing of Materials).

The focus of this research is limited to a certain type of plastic which is Polystyrene (***PS)*** only. This limitation is due to the lack of available products the researchers' may use since the other substances which are intended to be used can be easily availed through stores without the need for a special permit. And, also because it is one of the most common type of plastic that is legally open for self recycling or recycling without any special supervision from experts.

The information for the materials to be used about the sand like size, stone granules and others are based on standards since the sand to be used will only be manually sieved by the researchers themselves.

Significance of the study

This study will redound to the natural environment since it will lessen the plastic waste. Also, it will be the researchers' simple way of participating in global waste reduction. And, for the researchers to discover more about their field of competence. To the professionals involved in the construction industry, the study will provide knowledge about the viability of recycled plastic, Sand, Granular stone blocks as road base course materials. Although, the facility and machine that can be used are not yet available, this study can serve as an inspiration to future researchers to innovate and design a facility that will handle the innovative material to be used for its intended purpose. For others, this study is relevant for them to gain awareness about the production of a new base course material that is made from disposable products that are used inside their homes.

Method

The main material used in the making of the specimen is plastic.

Table 1. Table for Materials and Specifications

PLASTIC WASTE (polystyrene)	Foamed type Styrofoam.
SAND	River sand
WIRE MESH	Used as the molding container for the specimen
	Used as the reinforcement for the specimen
ACRYLIC THINNER	Substance used for dissolving the PS materials.
GRANULAR STONES	Size of Granular stone will ranged from 6mm to 15mm, and these volcanic rocks that are harvested somewhere in Pampanga said by our Expert contact Engr. Redenell Julian.

Procedure (for type A mix)

1. Collection and gathering of the materials to be used (Polystyrene, Sand, granular Stone).
2. Preparation of the materials.
    a. Cleaning of the plastic waste (to make sure that no dirt build-up is left on the plastic).
    b. Sieving of sand to harvest medium type sand.
    c. Preparing the ratio of each material for mixing
3. Take the container where the melting of plastic is to be done.
4. Pour 1 part acrylic thinner to the container.
5. Start transferring pieces of shredded polystyrene to the container
6. Transfer polystyrene materials and slowly stir to dissolve the material faster.

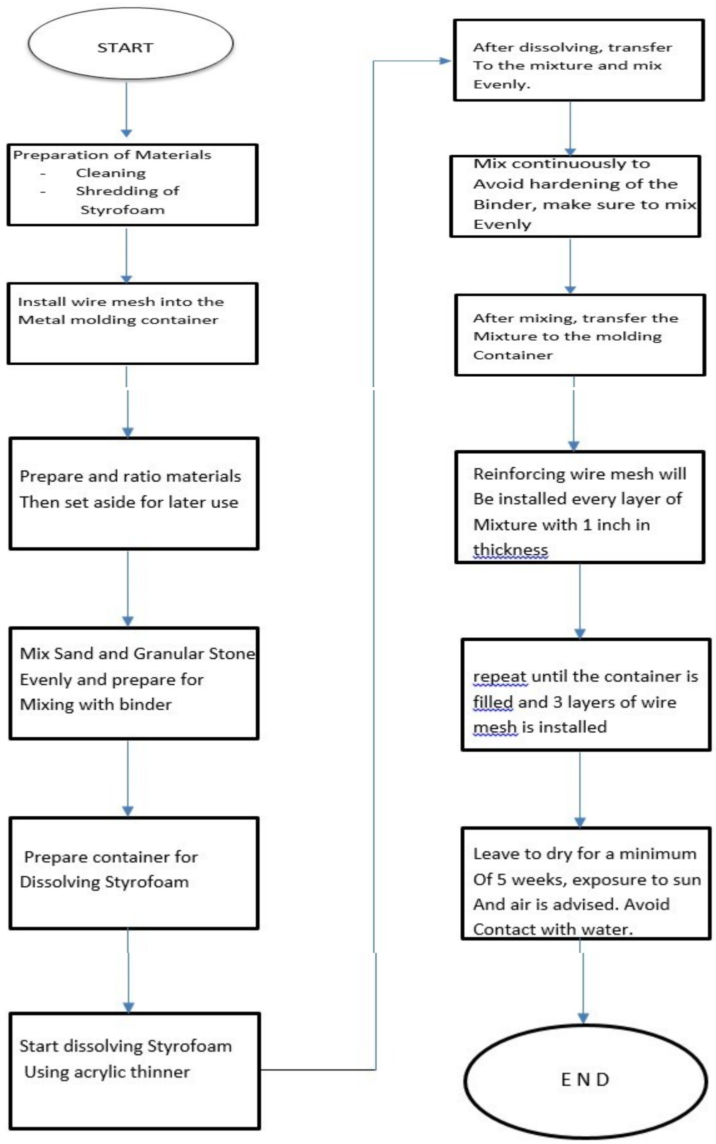
7. While on the process of melting, the container mold should be prepared for transfer.
8. Add 1/2 part of Sand and 1/2 part of Granular Stones to dissolved polystyrene and mix evenly, type A mix.
9. Transfer mixture to the molding container. Expose to sunlight and air to dry.
10. When hard enough, remove from mold and let sit under sunlight and air for few more days to dry and harden.

Mixture ratio for specimen is: 1/2 part Sand, 1/2 part Granular Stone, 7 parts Polystyrene, 1/2 part Acrylic Thinner

Procedure (for type B mix)

1. Collection and gathering of the materials to be used (Polystyrene, Sand, granular Stone).
2. Preparation of the materials.
    a. Cleaning of the plastic waste (to make sure that no dirt build-up is left on the plastic).
    b. Sieving of sand to harvest medium type sand.
    c. Preparing the ratio of each material for mixing
3. Take the container where the melting of plastic is to be done.
4. Pour 1 part acrylic thinner to the container.
5. Start transferring pieces of shredded polystyrene to the container
6. Transfer polystyrene materials and slowly stir to dissolve the material faster.
7. While on the process of melting, the container mold should be prepared for transfer.
8. Add 1/2 part of Sand and 1/2 part of Granular Stones to dissolved polystyrene and mix evenly, type A mix.
9. Transfer mixture to the molding container. Expose to sunlight and air to dry.
10. When hard enough, remove from mold and let sit under sunlight and air for few more days to dry and harden.

Mixture ratio for specimen: 1/2 part Sand, 1/2 part Granular Stone, 3 parts Polystyrene, 1/4 part Acrylic Thinner



Experimental Design

1. Preparation of materials
   - Polystyrene materials are cleaned thoroughly to make sure that it is clean and is free from excess dirt. After cleaning, polystyrene materials are to be shredded to small pieces.
2. Installation of Wire mesh
   - Since the designed molding container is open on all sides, wire mesh are to be installed around the container to hold the mixture. Wire mesh is also used because the mixture should be exposed to air while drying.
3. Ratio
   - To determine the ratio, shredded polystyrene is transferred to container and is to be filled up 7 times. For the river sand and granular stones, half-filled amount of the container is enough. And for the acrylic thinner, half liter is the amount needed to dissolve the shredded polystyrene. This ratio is for Type A. for type B, polystyrene will be reduced to 3 instead of 7, and acrylic thinner is only ¼ liter instead of ½ liter. Same amount of river sand and granular stone is needed.
4. Mixing
   - In a mixing container or in a clean surface, mix together river sand and granular stone evenly. After mixing, a hole in the center of the pile shall be created.
5. Dissolving container
   - Container should be made out of metal and should be clean.
6. Dissolving
   - Transfer Acrylic thinner into the container and start putting pieces of polystyrene into the solvent with continuous stirring to avoid hardening of the dissolved polystyrene.

7. After Dissolving
   - After dissolving all polystyrene, transfer the binder into the mixture of river sand and granular stones quickly.
8. Mixing
   - Mix together the sand, stone mix with the binder evenly, and quickly as the binder is quick to dry when exposed to wind.
9. Transfer to container
   - After mixing, transfer mixture into the molding container carefully.
10. Reinforcement
    - After every 1 inch thick mixture is transferred into the container. A reinforcing wire mesh must be installed.
11. Reinforcement
    - Repeat step no.10 until the container is filled and 3 layers of reinforcing wire mesh are installed.
12. Drying
    - After transferring mixture and installing reinforcements, the specimen is ready for drying, place the specimen in an open place with direct exposure to sunlight and wind. This will help to decrease drying time. Any type of waterproof covering must be used in to protect the specimen from water when it is raining. Don't try to move the specimen while drying as this may cause deformation and cracking. Leave for a minimum of 5 weeks for a completely dried specimen.

Details of the specimen

The specimen is a box-shaped block with a dimension of 1000 mm X 1000 mm and 101.6 mm for thickness. For the testing, 6 inches diameter and 12 inches for height of cylindrical samples were made and then were tested for

compression and flexural strength through a compression testing machine. A rectangular 6 x 6 x 21 inches sample was tested for Flexural strength. The specimen was made out of dissolved plastic wastes mixed with sand and granular stones molded through a wire mesh molding container designed for making the specimen itself. The specimen was of Jigsaw puzzle-like shape intended to create the interlocking properties with a mosquito wire mesh placed inside the specimens to resist any up and down motion due to discontinuity when laid out as base course in road construction.

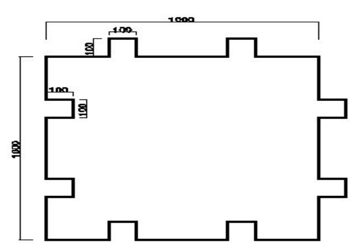


Figure 3. Specimen design

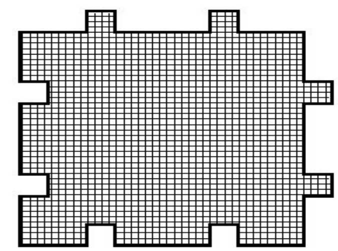


Figure 4. Specimen with wire mesh

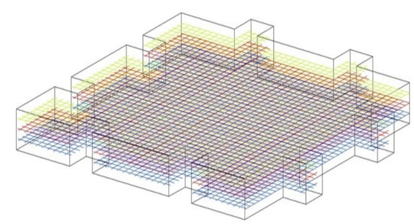


Figure 5. Isometric view of reinforced specimen

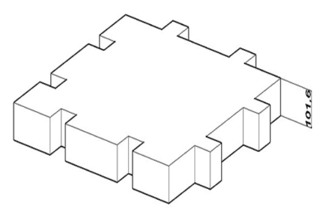


Figure 6. Isometric view of specimen structure

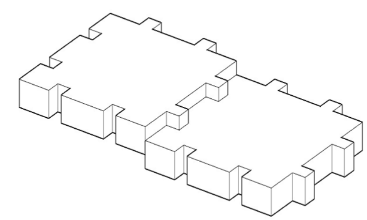


Figure 7. Final specimen design with the jigsaw puzzle interlocking feature

Results and Discussion

Compression Testing Machine is the main testing machine used for the specimen. Specifications are shown in the table.

Table 2. Test Specifications for Compression and Flexure

Test Material	Specification	Results
Compression Test Plastic Blocks	To determine the compressive strength of the specimen and to confirm the validity of the specimen for its designed use. This is the most common test done for concrete. But the researchers use it to test plastic. Also, compressive strength is the most important parameter in structural design (Farah Peter, 2016)	The compressive strength of the material is expected to reach or surpass the needed amount of compression to support the road.
Flexural Test Plastic Blocks	To determine the flexural or bending strength of the specimen. And to confirm the validity of the specimen for its designed use. One central load is used. Firstly, place each support on each side, then a central point is marked and the test is done on the specimen.	The tensile strength of the material is expected to reach the needed amount of bending to support the road.

Testing, Results, and Observations

The main purpose of this study is to prove the capability of the research material for commercial use and in this section, the testing, analysis of results, findings, and observations are to be discussed.

Background Data

A total of 18 cylindrical samples with a dimension of 6"(0.1524m.) in diameter and 12"(0.3048m.) for height, were made to be tested for compression strength. The curing time for the samples is 2 weeks, 4 weeks, and 5 weeks respectively. For each testing event, 3 samples are grouped and tested together to collect 3 different results and the average total is to be computed. Also, the weight of each sample was observed through the weeks of curing to determine whether the weight of the samples were decreasing or increasing in time. A total of 9 rectangular samples with a dimension of 6"(0.1524m.) in diameter and 6"(0.1524m.) for height and 21"(0.5334m.) for length, were made to be tested for flexural strength. The curing time for the samples is 2 weeks, 4 weeks, and 5 weeks respectively. For each testing event, 3 samples are grouped and tested together to collect 3 different results and the average total is to be computed. Also, the weight of each sample was observed through the weeks of curing to determine whether the weight of the samples we're decreasing or increasing in time.

Additionally, 1 sample specimen was buried underground for exposure to natural soil and possibly groundwater for further observation of the specimen.

1. To determine whether the contents of the specimen will affect the soil, the plants nearby, or show any discoloration on the soil surrounding it.

2. For further observations, 2 other samples that were already cured for 5 weeks were left alone exposed in the natural environment such as direct sunlight, exposure to air and even rain. This way, more information about the specimen's relationship to the environment were determined, as the research was aimed to be eco-friendly.

Results

The first section presents the results of the first set of samples for compression testing.

Notes Type A

- TYPE A = Compression Sample Specimen with the Ratio of 0.168 kg. Polystyrene, 0.00028 m^3 part, acrylic thinner, 0.00028 m^3 part, granular stones, 0.00028 m^3 part of sand.
- A.M stands for Average Weight in Kg and Slugs.
- A.PSI stands for Average PSI (strength)
- A.MPA stands for Average MPA (Strength)
- X mark stands for no-activity or no-data

Table 3. Compression Test Results for Type A mix (ENGLISH unit)

Compression Testing Results (Type A)											
Group	Day 1	Week 1		Week 2		Week 3		Week 4		Week 5	
	Average Mass	A.M	A.PSI	A.M	A.PSI	A.M	A.PSI	A.M	A.PSI	A.M	A.PSI
1	0.65 slug	0.48 slug	X	0.26 slug	5633 PSI	X	X	X	X	X	X
2	0.65 slug	0.48 slug	X	0.30 slug	X	0.25 slug	X	0.17 slug	5933 PSI	X	X
3	0.67 slug	0.50 slug	X	0.26 slug	X	0.22 slug	X	0.16 slug	X	0.16 slug	6366 PSI
Highest Total Average:			6366 PSI (Cured for 5 Weeks)								
Lowest Average Mass:			0.16 slug (Cured for 5 Weeks)								

Table 3.1. Compression Test Results for Type A mix (S.I. units)

Compression Testing Results (Type A)											
Group	Day 1	Week 1		Week 2		Week 3		Week 4		Week 5	
	Average Mass	A.M	A.MPA	A.M	A.MPA	A.M	A.MPA	A.M	A.MPA	A.M	A.MPA
1	9.55 kg	7.00 kg	X	3.75 kg	38.84 MPA	X	X	X	X	X	X
2	9.55 kg	7.00 kg	X	4.35 kg	X	3.60 kg	X	2.50 kg	40.91 MPA	X	X
3	9.75 kg	7.35 kg	X	3.80 kg	X	3.20 kg	X	2.40 kg	X	2.34 kg	43.89 MPA
Highest Total Average:			43.89 MPA (Cured for 5 Weeks)								
Lowest Average Mass:			2.34 kg (Cured for 5 Weeks)								

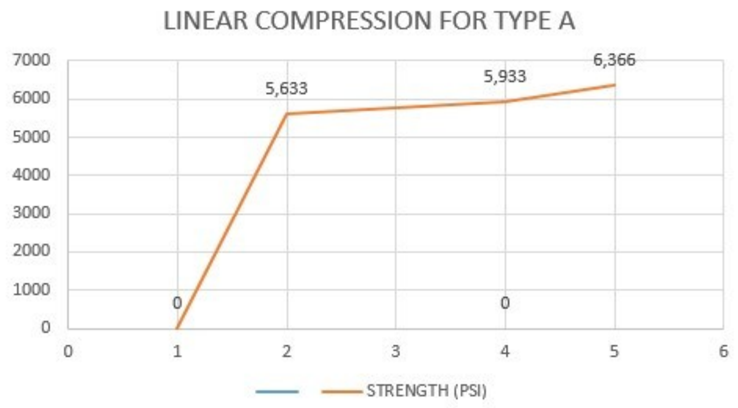


Figure 8. Graph showing the compression strength of the developed material (type A)

For this set of cylindrical samples (type A), as shown in Table 3. The specimen's weight started at line of 9's in kilograms, which account for the thinner that was used to dissolve the polystyrene materials which are still present and have not evaporated yet. The weight of the specimen was too heavy for a single piece. But, as shown in Table 3, the weight of the specimen group no. 3 continuously dropped from 9's to 2's after the 5th week from the time the samples were made. This is considered a good result from the weight observation. As for the compression strength results, as shown in Figure 8, the compression strength of specimen group no.1 that is 2 weeks cured reached an average of 5,633 PSI or 38,838.17 KN/m^2 with 5,700 PSI or 39,300.12 KN/m^2 being the highest within the group. This shows the big difference from the 2nd-week results of TYPE B samples that averaged 1500 PSI or 10,342.14 KN/m^2 upon testing as shown in Table 4.

Specimen group no.2 has shown a small difference but a higher result, reaching an average compression strength of 5,933 PSI or 40,906.6 with 6,500 PSI or 44,815.92 being the highest within the group. Still not completely dried on the inside, however, the last group of specimens was expected to reach a higher result since it is most likely to

have dried up completely. The result for the group no.3 was successful, the average strength gained for the 3rd testing activity reached 6,366 PSI or 43,892.02 with 6,800 PSI or 46,884.35 KN/m^2 as the highest within the group. The expected result of having the inside of the specimen to dry up was not met. Instead, the inside of the specimen was still not dried as observed from the tested samples. With this, it is concluded that the specimen from TYPE A can result in a higher strength but will require more time for the specimen to completely dry. This time the researchers obtained the required compressive strength that the base course has to satisfy, based on the results and the 3rd testing activity.

The second section presents the results of the second set of samples for compression testing.

Notes: Type B

- TYPE B = Compression Sample Specimen with the Ratio of 0.084 kg. Polystyrene, 0.00014 m^3 part acrylic thinner, 0.00028 m^3 part granular stones, 0.00028 m^3 part of sand.
- A.M stands for Average Mass in Kg and Slugs.
- A.PSI stands for Average PSI (strength)
- A.MPA stands for Average MPA (strength)
- X mark stands for no-activity or no-data.

Table 4. Compression Test Results for Type B mix. (ENGLISH unit)

Group	Day 1 Average Mass	Week 1 A.M	Week 1 A.PSI	Week 2 A.M	Week 2 A.PSI	Week 3 A.M	Week 3 A.PSI	Week 4 A.M	Week 4 A.PSI	Week 5 A.M	Week 5 A.PSI
Compression Testing Results (Type B)											
1	0.58 slug	0.47 slug	X	0.25 slug	1500 PSI	X	X	X	X	X	X
2	0.59 slug	0.47 slug	X	0.29 slug	X	0.25 slug	X	0.16 slug	4600 PSI	X	X
3	0.59 slug	0.47 slug	X	0.27 slug	X	0.22 slug	X	0.17 slug	X	0.16 slug	5520 PSI
Highest Total Average:	5520 PSI (Cured for 5 Weeks)										
Lowest Average Mass:	0.16 slug (Cured for 5 Weeks)										

Table 4.1. Compression Test Results for Type B mix (SI unit)

Group	Day 1 Average Mass	Week 1 A.M	Week 1 A.MPA	Week 2 A.M	Week 2 A.MPA	Week 3 A.M	Week 3 A.MPA	Week 4 A.M	Week 4 A.MPA	Week 5 A.M	Week 5 A.MPA
Compression Testing Results (Type B)											
1	8.50 kg	6.85 kg	X	3.65 kg	10.34 MPA	X	X	X	X	X	X
2	8.55 kg	6.90 kg	X	4.20 kg	X	3.60 kg	X	2.40 kg	31.71 MPA	X	X
3	8.55 kg	6.91 kg	X	3.88 kg	X	3.20 kg	X	2.45 kg	X	2.35 kg	38.06 MPA
Highest Total Average:	38.06 MPA (Cured for 5 Weeks)										
Lowest Average Mass:	2.40 kg (Cured for 5 Weeks)										

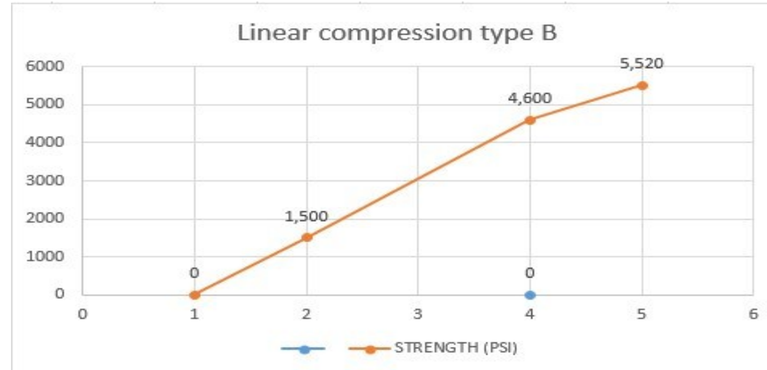


Figure 9. Graph showing the compression strength of the developed material (type B)

For this set of cylindrical samples (type B), as shown in Table 4. The specimen's weight started at line of 9's in kilograms, which account for the thinner that was used to dissolve the polystyrene materials which are still present and have not evaporated yet. The weight of the specimen was too heavy for a single piece. But, as shown in Table 4, the weight of the specimen group no.3 continuously dropped from 9's to 2's on the 5th week from the time the samples were made. This is considered a good result from the weight observation. As for the compression strength results, as shown in Figure 9, the compressive strength of specimen group no.1 that is 2 weeks cured, reached an average of 1,500 PSI or 10,342.14 KN/m^2 with 1,600 PSI or 11,031.61 KN/m^2 being the highest within the group. This is relatively low considering the load that road's base course carries. Since the specimen still has not dried on the inside, the results are fairly okay.

But, specimen group no.2 has shown a big change in strength after testing, reaching an average compression strength of 4,600 PSI or 31,715.88 KN/m^2 with 4,800 PSI or 33,094.84 KN/m^2 being the highest within the group. Still not completely dried on the inside, the last group of specimens was expected to reach a higher result since it is most likely to have dried up completely. The result for the group no. 3 was successful, the average strength gained for the 3rd testing activity reached 5,520 PSI or 38,059.06 KN/m^2 with 5,750 PSI or 39,644.85 KN/m^2 as the highest within the group. With this finding, it is concluded that the specimen's strength consistently increases by time. Although the maximum compressive strength is still not attained, the researchers were satisfied with the gained results of the first set of tests.

The third section presents the results of the set of samples for flexural testing.

Notes: Type A

- Compression Sample Specimen with the Ratio of 4.34 kg. polystyrene, 0.00619 m^3 part acrylic thinner, 0.00619 m^3 part granular stones, 0.00619 m^3 part of sand.
- A.M stands for Average Mass in Kg and Slugs.
- A.PSI stands for Average PSI (strength)
- A.MPA stands for Average MPA (strength) o X mark stands for no-activity or no-data.

Table 5. Result of Flexural Test for Type A mix. (ENGLISH unit)

Group	Flexural Testing Results (Type A)										
	Day 1	Week 1		Week 2		Week 3		Week 4		Week 5	
	Average Mass	A.M	A.PSI	A.M	A.PSI	A.M	A.PSI	A.M	A.PSI	A.M	A.PSI
1	1.40 slug	1.10 slug	X	1.00 slug	1333 PSI	X	X	X	X	X	X
2	1.37 slug	0.96 slug	X	0.87 slug	X	0.77 slug	X	0.67 slug	1700 PSI	X	X
3	1.46 slug	1.16 slug	X	1.03 slug	X	0.91 slug	X	0.75 slug	X	0.65 slug	1866 PSI
Highest Total Average:		5520 PSI (Cured for 5 Weeks)									
Lowest Average Mass:		0.16 slug (Cured for 5 Weeks)									

Table 5.1. Result of flexural test for type A mix (S.I. unit)

Group	Flexural Testing Results (Type A)										
	Day 1	Week 1		Week 2		Week 3		Week 4		Week 5	
	Average Mass	A.M	A.PSI	A.M	A.PSI	A.M	A.PSI	A.M	A.PSI	A.M	A.PSI
1	20.5 kg	16.00 kg	X	14.50 kg	9.19 MPA	X	X	X	X	X	X
2	20 kg	14.00 kg	X	12.75 kg	X	11.25 kg	X	9.75 kg	11.72 MPA	X	X
3	21.25kg	17.00kg	X	15.00 kg	X	13.25 kg	X	11.00 kg	X	9.50 kg	12.87 MPA
Highest Total Average:		12.87 MPA (Cured for 5 Weeks)									
Lowest Average Mass:		9.50 kg (Cured for 5 Weeks)									

For the results of the rectangular sample, as shown in Table 5, the specimen's weight started at line of 20's in kilograms, which account for the thinner that was used to dissolve the polystyrene materials that was still present and have not evaporated yet. The weight of the specimen was too heavy for a single piece. But, as shown in Table 5, the weight of the specimen group no.3 continuously dropped from 20's to 10's on the 5th week from the time the samples were made. This is considered a good result from the weight observation.

As for the flexural strength results of specimen group no. 1 that is 2 weeks cured reached an average of 1,333 PSI or 9,190.711 KN/m^2 with 1,500 PSI or 10,342.14 being the highest within the group. This result is relatively low considering the load that road's base course carries. Since the specimen still hasn't dried on the inside, the results are fairly okay. But, specimen group no.2 has shown a slight but higher change in strength after testing, reaching an average flexural strength of 1,700 PSI or 11,721.09 with 1,800 or 12,410.56 being the highest within the group. Still not completely dried on the inside as observed in the tested samples, the last group of specimens was expected to reach a higher result since it is most likely to have dried up completely. The result for group no.3 was successful, the average strength gained for the 3rd testing activity reached 1,866 PSI or 12865.62 with 2,000 or 13789.51 KN/m^2 as the highest within the group. With this, it is concluded that the specimen's strength consistently increases by time. This time the researchers obtained the required flexural strength that the base course has to satisfy.

Data Comparison

The researchers decided to take standard specifications and data for concrete pavements for them to be able to compare the collected results from the tests. And also with the help of their expert contact Engr. Redenell Julian, a Project Engineer who is experienced on road projects, the researchers were able to acquire more data

needed for the comparison. See Table 6 for the comparison of compressive strengths.

Table 6. Comparative Table for Compressive and Flexural Strength of Concrete Pavement.

Researchers' result (Highest attained) *specimen made originally for base course.*	Engr. Redenell Julian (Project Engineer) Minimum design used for his projects.	American Concrete Pavement Association (ACPA) (Minimum) *for heavy traffic load roadways*	American Association of State Highway and Transportation Officials (AASHTO) (Minimum)
6,366 PSI 43.89202 N/mm^2	3500 PSI 24.13165 N/mm^2	4000 PSI 27,57903 N/ mm^2	3000 – 4000 PSI 20.68427 – 27.57903 N/mm^2
1866 PSI 12.86562 N/mm^2	650 PSI 4.13685 N/mm^2	700 PSI 4.8263 N/mm^2	700 PSI 4.82633 N/mm^2

Specimen Type A Compression Strength Results vs ASTM Standards

According to the ASTM C39/ ASTM C39M, standard for concrete, dried or soaked at the time of loading (AASHTO t22), the nominal concrete strengths ranges from 14 to 42 MPA (2000 to 6000 psi) for the standard compression strength. And as shown in comparison to the standard strength of concrete and the gathered result for strength of the specimen, it is shown that the specimen reached the standard compressive strength that concrete must attain for it to be used in road construction.

Specimen Type B compression strength results vs ASTM standards

According to the ASTM C39/ ASTM C39M, which is for concrete, dried or soaked at the time of loading (AASHTO t22), for nominal concrete strength ranging from 14 to 42 MPA (2000 to 6000 psi) is the standard compression strength. And, as shown in comparison to the standard strength of concrete and the gathered result for strength of the specimen, it is shown that the specimen reached the standard compressive strength that concrete must attain for it to be used on road construction.

Specimen Type A Flexural Strength Results vs ASTM Standards

According to ASTM C293 for center-point loading (AASHTO t177), it is stated that the standard deviation for concrete flexural strength is up to 800 psi (5.5 MPa) for projects with a good control range. And, as shown at the table above, in comparison to the standard strength of concrete and the gathered result for the strength of the specimen, it is shown that the specimen reached the standard flexural strength that the concrete must attain for it to be used on road construction.

Summary, Conclusion, Recommendation

As the population of this planet grows, more people are having the urge to invest in their transportation, thus resulting in the addition of vehicular volume to the flow of traffic. The higher the volume of vehicles in the traffic means the higher the amount of load and stress that pavements have to carry. Thus, resulting in failures and further damages.

The proposed design of this study aims to improve the strength of the base of the pavements. Not only to improve the stress and load capacity of the pavement but also, to possibly extend the life span of roads. And with the use of recycled polystyrene materials, this study may highly

contributes to waste management.

The proposed new base course material blocks that are made out of polystyrene materials dissolved through the use of acrylic thinner, mixed with granular stones and sand was developed. These blocks are also reinforced with wire mesh for improved durability.

The developed specimen was proven to be durable and is hard, and with the presence of polystyrene on the mixture, it eliminates any sign of brittleness due to the polystyrene's tensile properties. Although the odor of the acrylic thinner used is unavoidable and may linger, the odor is proven to disappear after long time exposure to sunlight and air.

The process of dissolving polystyrene through contact with acrylic thinner is the method used in order to avoid releasing of toxic fumes into the air and as obtained in the study, is proven effective.

Conclusion

After all the design processing, gathering and comparing data, testing of material, and interpretation of the results gathered, the researchers put forward the following conclusions:

1. The proposed design is stronger than the existing base course materials currently being used in the Philippines. And, can support the pavement to resist a higher amount of load from passing vehicles, which may result in a longer life span of the road.

2. The designed material is concluded to be eco-friendly with no signs of soil disruption. But, proposed curing time must strictly be followed as the acrylic thinner components of the mixture need to completely settle and evaporate before application as a base course.

Recommendation

The researchers are proposing the following recommendations for more improvement and possible application of the study to other fields.

Other possible uses:

1. **Mortar**
   While on the process of finishing the final specimen, the researchers tried to use the excess mixtures on a couple of CHB as mortar and observed a positive result. The researchers believe that a separate in-depth study can make this idea more possible.

2. **Pavement**
   As the study is constantly being compared to the concrete mixture used on pavements, the researchers propose a separate study to improve the mechanical and physical properties of the specimen, as the surface of the specimen breaks easily when exposed to rain. The wearability of the specimen must be improved through further study.

3. **Bricks**
   Further improvement of the mixture to have a smoother finish, is going to be enough for this design to be used for making bricks as the durability of the specimen has been proven through this study. Perhaps, application of top coat may prove the feasibility for use as brick material.

Recommendation for improvements and innovations:

1. A separate study to further improve the curing time of the mixture by changing the design or looking for additives that will result in faster curing.

2. Acrylic thinner was used as the dissolving material for this study. The researchers believe that there are other possible materials or methods that can be used or done, to recycle polystyrene materials without causing harm to the environment.

3. Separate study for a smaller sizes of the specimen for a faster drying time.

References

www.philstar.com

en.wikipedia.org

wwf.panda.org/coraltriangle/news 2019

time.com/history-origins-recycling

www.thebetterindia.com (related literature)

Toolkit.communitymonitoring.org

www.google.com

www.youtube.com

ASTM – AMERICAN SOCIETY FOR TESTING OF MATERIALS

AASHTO- AMERICAN ASSOCIATION OF STATE HIGHWAYS AND TRANSPORTATION OFFICIALS

www.thebetterindia.com/43685/plastic-waste-in-road-construction-plasticman-india-prof-vasudevan/

*Anooshe REZAEE JAVAN, Hamed SEIFI, Shanqing XU, Yi Min XIE, (2016) p*ublished by the International Association for Shell and Spatial Structures (IASS).