Wolkite University

College of Engineering and Technology

Department of C*ivil Engineering*

Engineering Properties of Plastic Waste as a Binding Material

Tewodros Ayalew Mekonen[1], Daniel Teshome Worku[2], Kaleab Birhanu G/maryam[3]

, Desta Demsew Birhanu[4], Tekll Geremew Deneke [5], Kidanemariyam Atnafu[6],

Advisor/s

Mr. Desalegn Gamini

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[1] Wolkite University, Civil Engineering Department, ID Number ENGR /879/08

[2] Wolkite University, Civil Engineering Department, ID Number ENGR /235/08

[3] Wolkite University, Civil Engineering Department, ID Number ENGR /492/08

[4] Wolkite University, Civil Engineering Department, ID Number ENGR /266/08

[5] Wolkite University, Civil Engineering Department, ID Number ENGR /845/08

[6] Wolkite University, Civil Engineering Department, ID Number ENGR /517/08

Wolkite University, College of Engineering and Technology

Civil Engineering Department

As members of the examining board of the final B.Sc. open defence, we verify that we have read and evaluated the final BSc thesis prepared by Tewodros Ayalew Mekonen, Daniel Teshome Worku, Kaleab Birhanu g/maryam, Desta Demsew Birhanu, Tekll Geremew and Kidanemariyam Atnafu entitled **Engineering Properties of Plastic Waste as a Binding Material,** and recommended for acceptance as a fulfilment of the requirement of **B.Sc. in Civil Engineering**

Chairman/Coordinator	Signature	Date
Advisor	Signature	Date
Internal Examiner	Signature	Date

Preface

This paper is a report as a part of fulfilment for Bachelor of science in Civil Engineering. The study is conducted by: - Tewodros Ayalew Mekonen, Daniel Teshome Worku, Kaleab Birhanu g/maryam, Desta Demsew Birhanu, Tekll Geremew and Kidanemariyam Atnafu.

Abstract

Disposal of plastic waste in environment is considered as big problem due to its very low biodegradability and presence in large quantities. The abundance of different types of waste plastic is a major problem for the sustainability of the environment by polluting rivers, land, road, oceans, as well as it increases global warming. Even there is different type of plastics, the paper focus on the polyethylene terephthalate (PET) plastic. Therefore, finding alternative methods of disposing these wastes by using friendly method is becoming a major research issue. As a result, the paper studies the engineering property of waste plastic as a binding and construction material instead of cement. In order to answer the research question, plastic waste was prepared, melt and moulded to the desired shape, similarly compressive strength tests were conducted in laboratory. Finally, it indicates how the terephthalate (PET) plastic waste can be used as a binding and construction material with property of lightweight, flexible, strong, moisture-resistant, cheap and easily available and can make it as a binding to replace cement or alternative material to many existing composite construction materials like bricks, tiles, terrazzo etc.

Acknowledgment

We would like to thanks our almighty God. Special thanks to Eden drinking water producing company for their willingness to give us waste plastic bottle. And also, we have a great thanks to Wolkite Poli-technical college specially for Mr. Adisu in manufacturing facility help us starting from preparation of mould up to final work.

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Acronym

PET: - Polyethylene terephthalate

HDPE: - High density polyethylene

LDPE: - Low density polyethylene

PP: - Polypropylene

PVC: - Polyvinyl chloride

PS: - Polystyrene

1 Introduction

1.1 Background

Today, the plastic materials which are largely in use in shopping industry around the world are polyethylene plastics. In developing country like Ethiopia, most people have not enough knowledge to use non-biodegradable plastic wastes like water bottle, bags etc.

Poor disposal of non-biodegradable plastic wastes causes environmental pollution such as reduce the aesthetical condition of the environment, cause serious toxicological impacts on human and living organism at the surrounding. Example when we see around Wolkite and Gubre town there is a lot of non- biodegradable plastic wastes at a side of roads, inside ditches (it affects the drainage system of the city).

Generally, to reduce the above risk as well as to create job opportunities using plastic wastes on the production of light weight construction material, we decided to do this research.

1.2 Research question

This paper will answer the following research question

What will be the Engineering properties of PET plastic waste as a binding for construction material like partition wall and finishing material (tiles, terrazzo etc.) prepared from a recycled-waste-plastics and pumice or sand (fine or coarse aggregate)?

1.3 Objective

1.3.1 General objective

The main objective of this paper is to compare and contrast the difference between the Engineering properties of construction material that produce using cement and waste plastic as a binding material respectively.

1.3.2 Specific objective

The specific objective of this paper is to investigate the Engineering property of PET plastic waste as a binding with sand for light weight construction material specifically, terrazzo which prepared from a mix of melt recycled-waste-plastics and river sand (i.e., compressive strength).

Hypothesis

If the amount of plastic in plastic to sand ratio increases, the compressive strength of the material will be increase and also the hot mix of plastic waste with sand will need large amount plastic waste relative to sand.

1.4 Significance of the study

The significance of this paper is to reduce plastic waste from the environment, re using this waste plastic in place of cement for manufacturing non-structural building material and also creating job opportunity.

1.5 Scope of the study

The main objective of this study is to determine the engineering property of PET plastic waste as a binding material for light weight building construction material (non-structural part) in Ethiopia as well as in the world because this PET plastic has the same physical and chemical properties throughout the world. However, the scope of this study is limited to only PET plastic material. And also, this study does not include chemical properties of waste plastic.

1.6 Limitations

There are different types of waste plastics around us. Such as Polyethylene terephthalate (PET), High density polyethylene (HDPE), Polyvinyl chloride (PVC), Low density polyethylene (LDPE), Polypropylene (PP), Polystyrene (PS) etc. But this paper only focuses on Polyethylene terephthalate (PET) plastic waste. And also, the study will not investigate the chemical and physical properties of PET plastics rather than it takes from literature review. Since the laboratory work or sample preparation is made manually, there is evaporation that may affect the strength and also, the temperature was not controlled. This paper also did not include the tensile and flexural test due to functionality of the equipment. In addition to that limited number of specimens was used, due to finance, time, and availability of machineries.

1.7 Organization of the paper

This study organized into six chapters. The first chapter focuses on the introductory part of the study, which includes background of the study, statement of the problem, objectives, significance, scope and limitation of the study. The second chapter contains literature review part of the study in which theoretical literatures related with the issue were incorporated. The third chapter deals about the research methodology: research design, approach and method; sources of data, data collection methods as well as analysis.

And the fourth chapter deals about the data analysis and interpretation in the laboratory. The fifth chapter deal about the decision part of the research. Finally, the six chapter includes conclusion and recommendations.

The following figure (Fig. 1.1) shows the organization and structure of the paper.

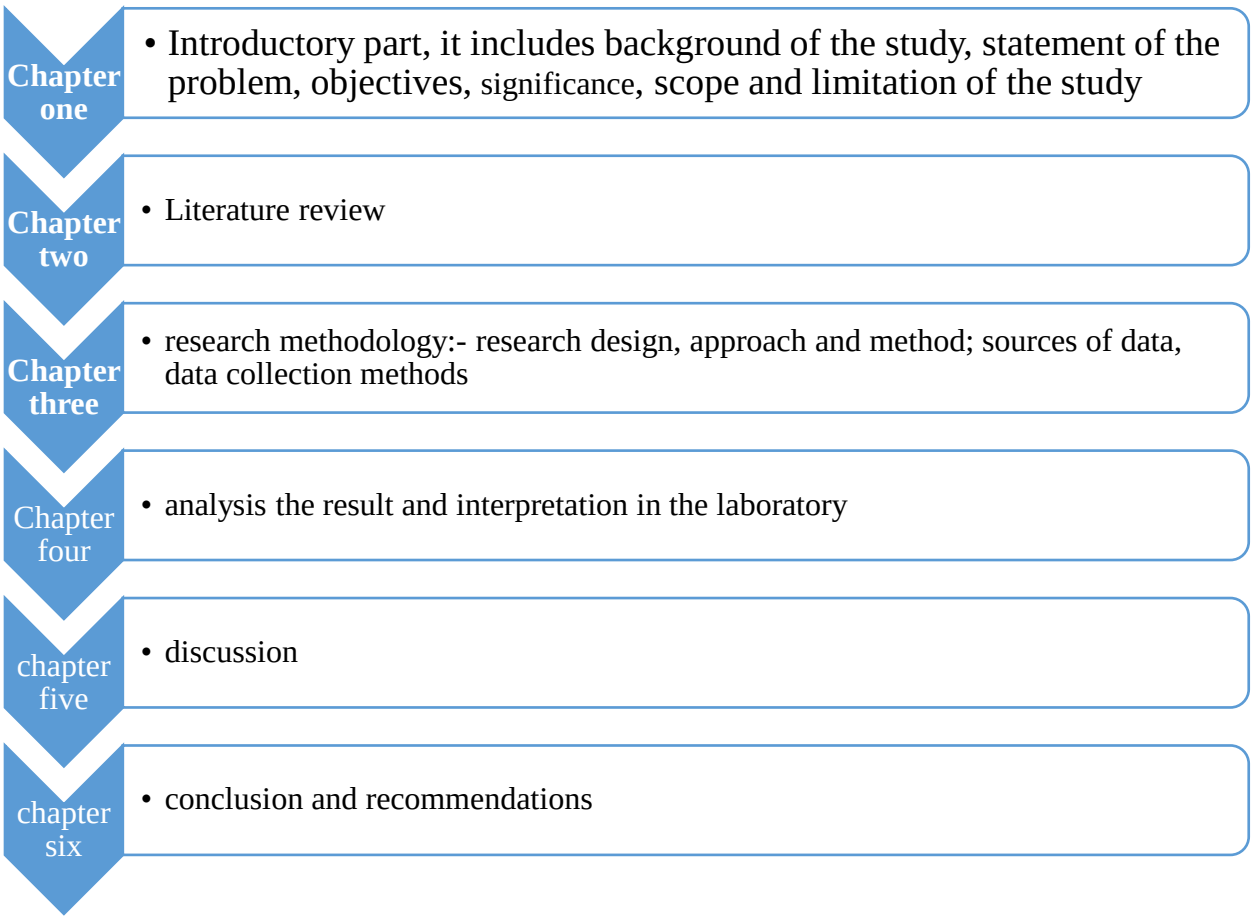


Figure 1.1 Organization and structure of the paper.

2 Literature review

2.1 Introduction

Plastics are generally categorized as Thermoplastics and Thermoset Plastics. Thermoplastics can be heated up to form products and then, if these end products are re-heated, the plastic will soften and melt again. These include PET, HDPE, LDPE, PP, PVC, PS etc (Shiri et al., 2015). In this paper we focus on the PET (polyethylene terephthalate) plastic waste, because thermoset plastics are always remaining in a permanent solid state do not soften easily, it needs high temperature.

polyethylene terephthalate (PET) bottles have taken the place of glass bottles as storing vessel of beverage due to its lightweight and ease of handling and storing. As the beverage consumption increases drastically, the production of PET bottles increased exponentially as it (Choi et al., 2005).

2.2 Properties of PET plastic

Polyethylene terephthalate (PET) is a general-purpose thermoplastic polymer which belongs to the polyester family of polymers. Polyester resins are known for their excellent combination of properties such as mechanical, thermal, chemical resistance as well as dimensional stability (Sulyman et al., 2016). PET is one of the most recycled thermoplastics, and has the number "1" as its recycling symbol. Recycled PET can be converted to fibres, fabrics, sheets for packaging, manufacturing automotive parts and construction material. PET is highly flexible, colourless and semi-crystalline resin in its natural state (Sulyman et al., 2016). Depending upon how it is processed, it can be semi-rigid to rigid. It shows good dimensional stability, resistance to impact of moisture, alcohols and solvents. Plastics are commonly used substances which play an important role in almost every aspect of our lives (Sulyman et al., 2016). The highest number of plastics is found in containers and packaging's (i.e., bottles, packaging, cups etc.), but they also are found in durables (e.g., building materials, furniture, etc.) and disposable goods (e.g., medical devices). Diversity of plastics applications is related with their specific properties, low density 1.38 g/cm^3 at 20^{0}c, easy processing, good mechanical properties, good chemical resistance, excellent thermal and electrical insulating properties and low cost (in comparison to other materials) (Sulyman et al., 2016). The PET material is heat-resistant until 180 °C, it does not decrease in strength, its melting temperature is around 260 °C (Gergely, 2017)

2.3 Recycling PET plastic waste

Currently, several studies deal with the utilization of recycled plastic as a binder for concrete. Recycled PET is used for this purpose. This polymer is currently used for production of beverage bottles and food packaging (Ge et al., 2014). Millions of tons of PET bottles are produced every year and it is desirable to deal with the utilization of this polymer, because PET is not biodegradable. The utilization as a binder in concrete is an effective way of recycling, which also leads to cement saving in the construction industry (Ge et al., 2014). This cement saving helps to reduce the consumption of raw materials and negative effects on the environment. A disadvantage is the expensive process of recycling of waste PET and its treatment before using as a concrete binder. Production costs are significantly lower, when another manufacturing process is selected cut pieces of raw PET waste are heated together with the filler and melted. However, only few studies deal with this technology (Ge et al., 2014).

2.4 River sand

Sand is a naturally occurring granular material composed of finely divided rock and mineral particles. It is defined by size, being finer than gravel and coarser than silt (Mekonnen, 2018)The sand from river due to natural process of attrition tends to possess smoother surface texture and better shape. It also carries moisture that is trapped in between the particles. These characters make concrete workability better. However, silt and clay carried by river sand can be harmful to the concrete. Another issue associated with river sand is that of obtaining required grading with a fineness modulus of 2.4 to 3.1 (Elavenil & Vijaya, 2013).

Sand is naturally occurring granular material which is composed of mineral particles and finely divided material. The composition of sand varies depending on the local rock conditions and sources, but the most constituent of sand in inland continental settings and non-tropical coastal region is silica dioxide (Sio_2) in the form of quartz, and the properties of river sand listed on Appendix C. (Dinesh, 2016).

3 Research methodology

3.1 Introduction

PET is distinguished by excellent performance under static and dynamic load, retaining dimensional stability even at elevated temperature. The surface of moulded PET is glassy, hard, and abrasion resistant, with low coefficients of friction. It has low moisture absorption, allowing the material to maintain excellent dimensional stability through extremes of temperature and high humidity and also it is good electrical insulation properties, PET has found use in many electrical applications (Archna & Vinutha, 2015).

3.2 Research design

There are two types of research approaches, these are: - quantitative and qualitative. Quantitative study is a study where purely quantitative data and analysis techniques are adopted while qualitative approach makes use of purely qualitative data and analysis. This paper includes both qualitative and quantitative approach.

3.2.1 Study Area

The study was conducted at Wolkite and Gubre, Ethiopia. Wolkite is the administrative centre of the Gurage zone (Figure 3.1). The administrative centre of the Gurage zone is a part of the south nation nationalities and people region(SNNP), this town has the altitude and longitudinal of $8^0$17'N and $37^0$47'E and the elevation between 1910 and 1935 meters above sea levels (Anmut et al., 2017).

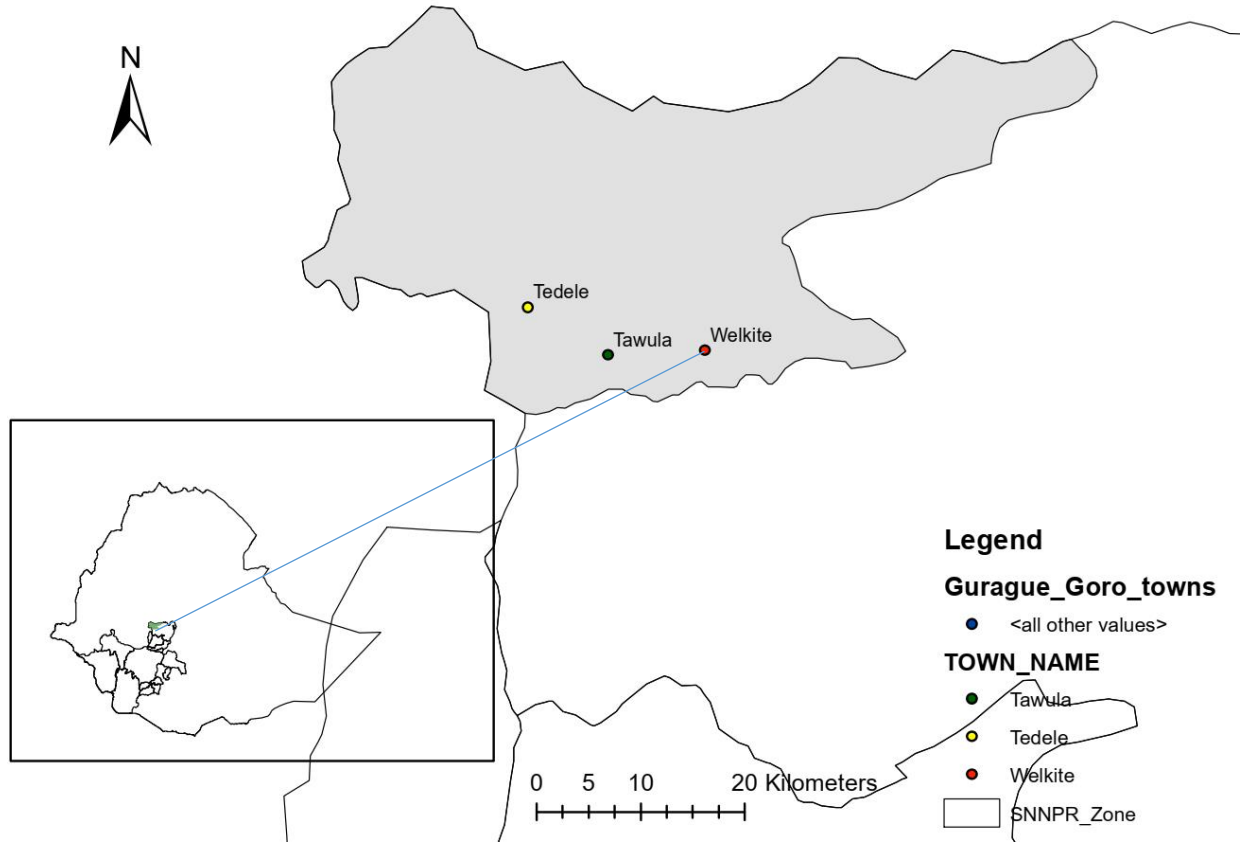


Figure 3.1 Study Area

3.3 Sources of Waste Plastic (PET)

PET is used as a raw material to make packaging materials such as bottles and containers for packing a wide range of food products and other consumer goods. Examples include soft drinks, alcoholic beverages, detergents, cosmetics, pharmaceutical products and edible oils. PET is one of the most commonly used plastic type. (Ge et al., 2014) There for, we prepare these waste plastics from the one of the above listed materials (Figure 3.2).

Figure 3.2 waste PET Plastics

3.4 Overall framework of the study

The main aim of this study is to evaluate the engineering property of plastic waste used as a binder in production of construction material. In order to answer the research questions, firstly collected used plastic bottles (PET) from companies. The PET was then used to prepare a specimen tile with PET as a binder. Finally, laboratory test is conducted on prepared samples (Figure3.3).

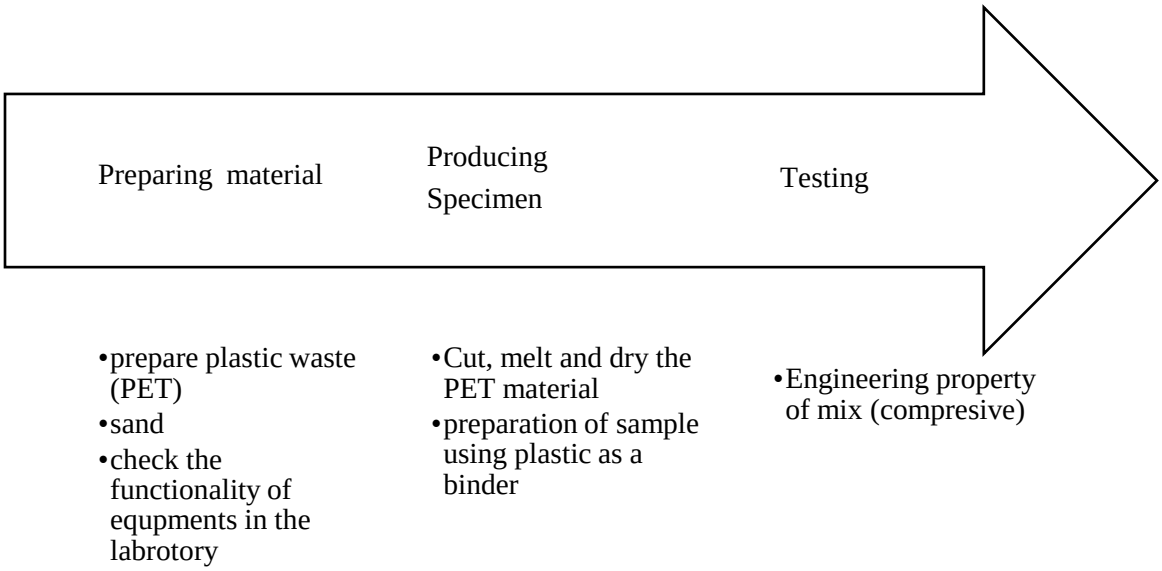


Figure 3.3 Overall framework of the study

3.5 Data Collection

Since most research involves the collection of data, there are several data collection methods such as direct or primary data collection including questionnaires, direct observations, interview and focus group discussion and indirect or secondary data collection. For this paper work focus on the direct observation of the study area as data collection method. Then finally evaluate their suitability under different circumstance.

3.5.1 Data Analysis

Now a day there are a lot of plastic wastes at the environment like plastic bags and water, foods, pharmaceutical and any other chemicals plastic bottle at a side of road and inside the ditch. This plastic has not any advantages for the surrounding society and considered as waste material. Generally, the plastic waste material is polluting the environment and mainly affect the drainage system of the road side (ditch). The society has no enough knowledge to manage these waste materials, that's why we look for a solution.

3.5.2 Overall procedure of preparing samples and testing

This paper followed a series of basic stages in preparing samples for testing. Firstly, used plastic bottles was collected from Eden drinking water producing Company. Secondly, the samples were sorted or identified which helps to separate the needed material from the slovenly one and the PET part cut in to small pieces and washed. Thirdly, washed PET was dried. Next, cut pieces were melt and blend with river sand in a predetermined mix ratio. Finally, hot mix is placed in a standard cube and terrazzo mould and allowed to cooled (Figure 3.4 and 3.5).

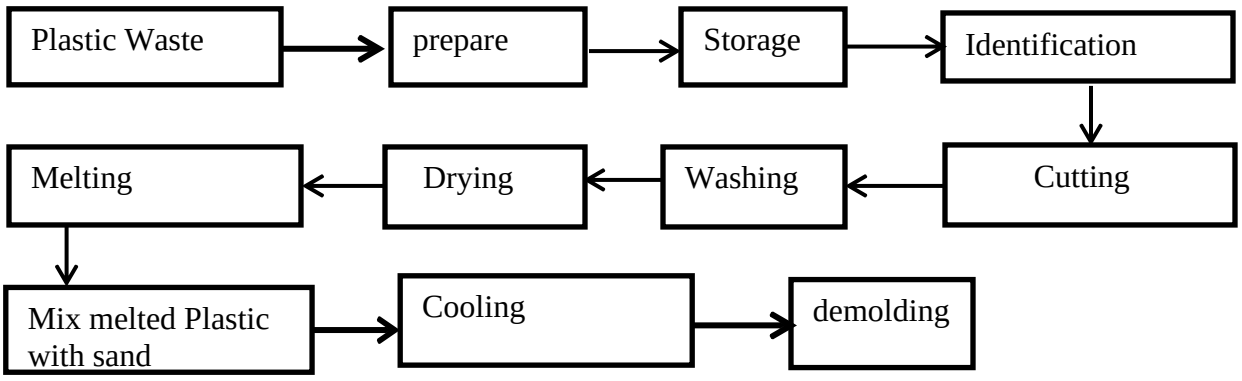
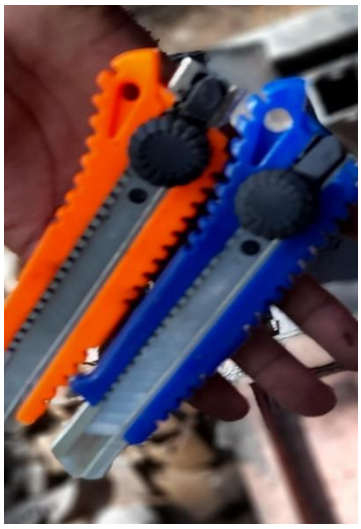


Figure 3.4 General procedure of the study

a) prepared PET plastic bottles



b) cutting equipment

c) cutting PET bottles

a) melting and mixing

b) readily melted

c) moulding

d) demoulding

Figure 3.5 procedure of the study at laboratory

3.6 Sample

It is a portion or a part of an object taken from a larger group of an object or item that used for testing, studding, identifying the properties of this sample and to conclude and generalize the finding from the sample about the mass item.

3.6.1 Sample size

Actually, for this paper two types of sample size determination for cube test or compression test of the mixed design and sample preparation for tile.

a) terrazzo mould

b) Cube mould

Figure 3.6 Sample size

3.6.2 Specimen preparation

As discussed before (figure 3.4 and 3.5) about the methodology and procedure of the research, first ready enough amount of waste plastic for specimen preparation and material test. If the plastic is dirty it must be cut in to smaller pieces either manually or using machineries, then wash and after drying it must melt and mix with sand. Finally moulded in to different shape for test and sample material.

a) Measure before melt

b) melting by fire

C) mixing sand

d) ready to moulding

e) moulding

f) mould

Figure 3.7 sample preparation

3.6.3 Mix design

In this test there are different types of mix design used for both cube test as well as sample terrazzo test to study their properties by trial. See table 3.1.

Table 3-1 Mixed ratio

Plastic to sand ratio	Cube test	Terrazzo test
100% plastic	✓	✓
1:1	✓	✓
2:3	✓	✓
1:3	✓	✓

3.6.4 Test of material properties

The material that used for this research is only PET waste plastic and natural sand. The chemical and physical properties of PET waste plastic can't be included as try to show in chapter one at limitation stage, and also, river sand properties used with melted plastic that takes from chapter two literature reviews.

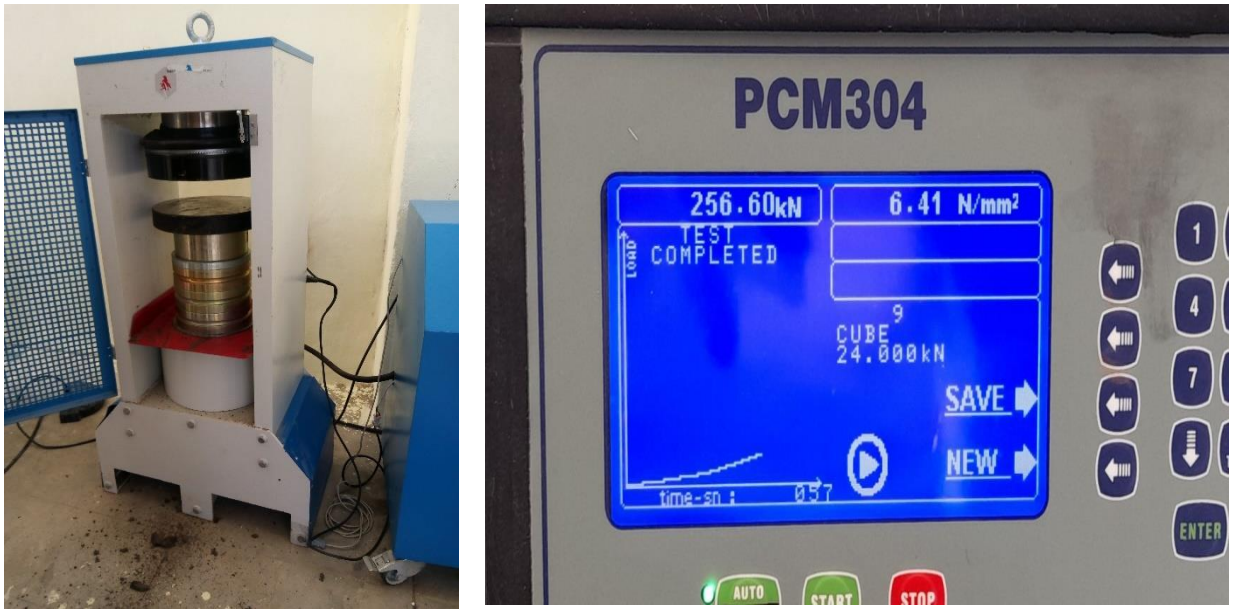
4 Result

4.1 Introduction

Material testing is performed to provide different information about the tested material or prepared sample, so that the data obtained during the test provides facts about the material and give broad understanding of the product. It measures the characteristics and behaviours of the material by tests a compressive strength. It expresses how the material can stand against applied load without failure. The test was included 15*15*15cm cube and 40*40cm terrazzo material.

4.2 Method of data analysis

In the laboratory test there are two types of data analysis mechanisms by record the data directly from the machine and by print out mechanism (Figure 4.1). So, for this paper method of data analysis from lab by read directly from machine.



a) Compressive test machine b) Test result

Figure 4.1 Compressive test

4.3 Laboratory test result of samples

There are two types of samples produced in the laboratory this are cube test and sample terrazzo tile test. Two specimens are used for each test and each ratio for cube test. Four different ratios of plastic and river sand was used in this paper. (Appendix A). From this ratio the first ratio was failed both cube and terrazzo test that is without sand hundred percent (100%) PET plastic (Figure 4.2).

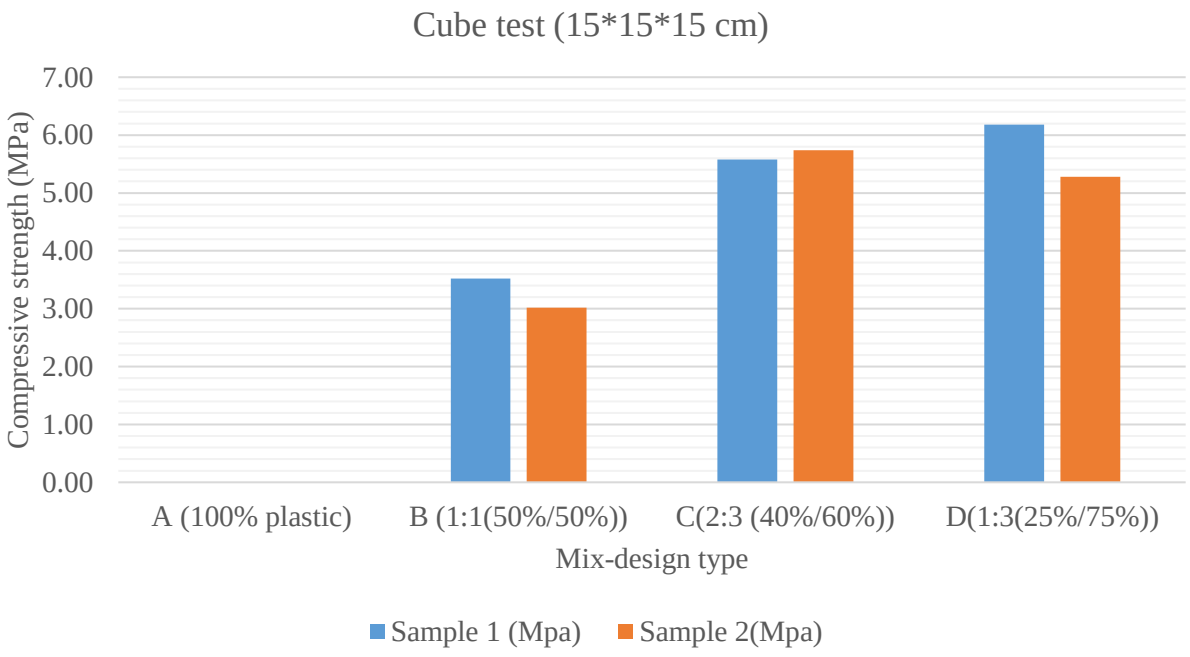


Figure 4.2 Results of compressive strength of cubes on different mixes

4.4 Laboratory test result of terrazzo

Compressive test of terrazzo was conducted at laboratory with different mixed ratio.

(Appendix B)

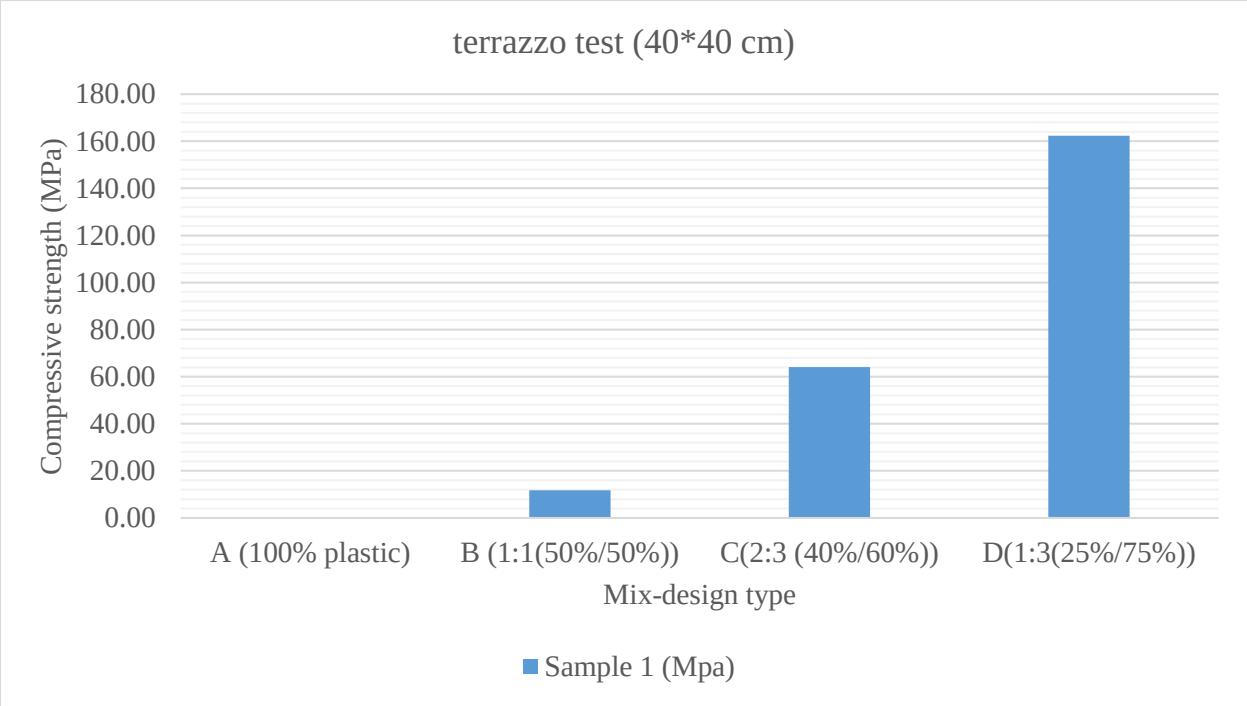


Figure 4.3 Results of compressive strength of terrazzo on different mixes

5 Discussion

The main aim of this paper was to evaluate the use of plastic bottles as binding material in hot mix for cubes and terrazzo tiles and deals about its properties. From our field observation a used plastic bottle is a waste that is not properly recycled but littered in roads and farmland around Wolkite, Ethiopia. A study in South Africa has already described a similar challenge associated with littering and mismanagement of used plastic bottles. Deploying new construction technologies and materials has solved many environmental problems caused by building waste materials, namely saves energy and natural resources, and reduces environmental pollutants through reusing and recycling building materials and increasing lifespan and durability of the materials (Afzali & Hamzehloo, 2018).

Results of compressive strength of cube, showed that the first day and third day compressive strength was compared to each other has small difference. This shows melted waste plastic as binding material in place of cement doesn't take extended curing date as well as it has small initial setting time compared to concrete and mortal that used cement as binder. The proportion of concrete ingredients given in the "Standard mixes for ordinary Structural Concrete" of this specification or proportions obtained by tests shall be used for concrete mixing, Where the proportion of ingredients given in the concrete class section of the specification is not applicable, trial batches shall be made and the mix from which the desired strength is established by testing shall be used for the works (ERA, 2015).

Tiles shall be thoroughly soaked in water for a minimum of 15 minutes before laying and taken out just before use. Tiles shall be left undisturbed for 24 hours. Tiles shall be topped with cement fine aggregate mortar mix 1:3 to a minimum thickness of 5mm distributed uniformly. The flooring shall be wetted for seven days and left to cure for 28 days (ERA, 2015). From our laboratory observation we have four different terrazzo mix ratio and from those the best compressive result recorded on the 1:3 ratio of plastic to sand respectively. The strength of concrete increase with age see Appendix D. Whereas for plastic mortar slightly has no effect on strength as we see from first and third-day experiment result. Concrete structure cannot be harm by high temperature, it resists fire but plastic construction material resist effect of temperature up to 180^{o}c beyond this it starts to deform.

Generally Concrete takes much time (24 hour and more) to demold the product, but 15 minutes is enough in case plastic terrazzo. This leads it to produce much more than the one made with cement and no water is needed to make the floor tiles. The production of these floor tiles reduces the amount of municipal solid waste. The rise in temperature and fall in temperature does not affect the floor tiles so it can be used in hot and cold regions. The climatic changes do not affect the size, shape and color is uniform throughout its body. So, it provides good aesthetic appearance. Moreover, if the cement is exposed to wet air it losses its property and become unusable (Prasad, n.d.). But no wet air has impact in case of plastic waste. Once cement made terrazzo cannot be re-used, but it can be recycled and re- used in plastic terrazzo, also it takes less amount of money to produce compared with that of cement made terrazzo. Moreover, it is Ecosystems friendly (decreases the pollution of the environment).

6 Conclusions & Recommendations

6.1 Conclusion

Every society needs to be cleaner and healthier to live in. But specially in developing country a plastic wastes that litter streets, farm lands and choke gutters or ditches which causes breeding grounds for mosquitoes and flies, which then causes malaria and cholera to the people. So, this paper conclude about recycling of plastic wastes will contribute to reducing or preventing the diseases associated with the plastic wastes. Society with healthy people will contribute to better development.

Generally, from this paper we conclude that compressive test of both cube and terrazzo test of melted waste plastic with natural river sand, has good result as the ratio of sand increases as seen from the sample test. And also, this research concludes that the melted plastic waste which was only without sand for both cube and terrazzo test was failed (when 100% waste plastic used). From hypothesis of the research the assumption of the sample preparation will use large amount of waste plastic but the truth is it needs small amount of melted PET plastics. And also, the research proves that when the amount of plastic increase in the plastic to sand ratio the strength of the materials decreases and becomes zero at the last.

Finally, from the experiment good compressive strength test result was recorded for the ratio of 1:3 (25%,75%) waste plastic to river sand respectively by volume, and summarize about the setting time of hot mix terrazzo and cube that need fifteen and half hour respectively to demoulding or to attain their permanent shape, so it is short setting time with compared to cement based terrazzo.

6.2 Recommendation

This research is interesting to know about the behaviours of waste plastic in engineering aspect by testing different properties actually its compressive and tensile strength by mixing the melt plastic with proportioned sand. But we have faced different problem, specially related to covid-19 diseases. Until we were here in the campus before we left from the university there was good progress on this paper. Whereas after we left the university since this research is group work, we have no time to communicate and analysis data about the paper because we were limited by living area, electricity for rural area, network (connection) and command post related to covid-19.

This paper more focus about lab test rather than interview or questionnaires that's how not to reduce the load at home. After we return to the campus, we start this paper work again from the begging. The time given to perform this paper is so short the idea of the research needs time. Due to this case, we cannot collect and wash waste plastic from the surrounding but we ask the sponsor with letter from Eden drinking water manufacturing company and they were voluntary to help us and give around 800 waste plastic.

The other obstacle of this research was the arrangement of laboratory machineries and instruments in the university. The instrument is available without functionality. The final decision was to move Wolkite Poli-technic collage to help us for this paper laboratory work. For the same manner the Wolkite Poli-technical collage wanted machines and equipment's are not functional for example washing, melting, and mould vibrating machineries. At the last we decided to perform the research manually.

Generally, the research was not run as we wish due to the shortage of time. When we start this paper work we assume to test the engineering properties of plastic wastes with different ratio of sand as well the functionality of this test in real world by producing the sample building material like tile, terrazzo etc. (i.e., the paper includes the project.)

Further study: This paper doesn't include tests like tensile and flexural, which determines its tension resistance and failure point. These tests must have to further studies in order to identify its property intensely. The paper contains limited amount of specimen compared with the required, it is well if more specimen is prepared and conducted in laboratory. The melting process of the PET plastics is accompanied manually which leads towards evaporate particles of the plastic, this may lead the plastic to loss its property, thus it is better to conducted with gauge oven, as well as the water absorption, texture, particle size distribution, Soundness and silt content of river sand that used in the laboratory needs further study.

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Appendix

Appendix A: Laboratory report on compressive strength of cubes

Plastic to sand ratio	Cube test (15*15*15 cm)				
	Sample-1		Sample-2		Mean result Compressive strength (MPa)
	Load (KN)	Stress (N/mm^2)	Load (KN)	Stress (N/mm^2)	
100% plastic	0	0	0	0	Fail
1:1(50%/50%)	79.42	3.52	68.06	3.02	3.27
2:3 (40%/60%)	125.62	5.58	127.2	5.74	5.66
1:3(25%/75%)	139.14	6.18	119.1	5.28	5.73

Appendix B: Laboratory report on compressive strength of tiles

Plastic to sand ratio	Terrazzo test	
	Sample-1	
	Load (KN)	Stress (N/mm^2)
100% plastic	0	0
1:1(50%/50%)	47.22	11.81
2:3 (40%/60%)	256.6	64.15
1:3(25%/75%)	649.02	162.3

Appendix C: properties of river sand

No	Experiment	Result
1	natural water content (%)	10.7
2	specific gravity	2.48
3	unit weight(γ)	1.59
4	fineness modules	2.89

Appendix D: Compressive strength of concrete at varies age ((International SP, 1995))

Age	Strength by percent
One day	16%
Three days	40%
Seven days	65%
Fourteen days	90%
Twenty-eight days	99%