ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY (AAiT)

SCHOOL OF CHEMICAL AND BIO ENGINEERING

Utilization of High Density Polyethylene Wastes for the Production of Terrazzo Tiles

A Thesis Submitted to the School of Chemical and Bio Engineering, in Partial Fulfillment of the Requirements for the Degree of Master of Science in Chemical Engineering (Under Process Engineering Stream)

By: Shimelis Mekonnen

Advisor: Dr.Beteley Tekola

Addis Ababa, Ethiopia

October, 2018

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Aproved by Bord of Examinors: October, 2018

Signature Date

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School Dean/PG Coordinator Signature Date

DECLARATION

I declare that this thesis entitled *"Utilization of High Density Polyethylene Wastes for the Production of Terrazzo Tiles'' has* not been submitted in any form for another degree, diploma or an award at any university or other institution of the tertiary education. Whenever contributions of others are involved, every effort is made to indicate this clearly, with due reference to the literature and discussions. Information taken from published and unpublished work of others has been acknowledged in the text and a list of references is given. The work was under the guidance of Dr.Beteley Tekola (Ass. Professor) instructor of AAiT in Addis Ababa University, School of Chemical and Bio Engineering.

Name: Shimelis Mekonnen

Signature: _______________

Date of Submission: October 29/ 2018

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LIST OF ABBRAIVATIONS, ACRONYMS AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
ANOVA	Analysis of Variance
ASTM	American Standard Testing Method
BBD	Box Behneken Design
DSC	Differential Scanning calorimetry
FTIR	Fouriers Transformation Infrared Spectroscopy
HDPE	High Desnsity Polyethylene
LIDI	Leather Institute Development Institute
LDPE	Low Density Polyethylene
MIT	Massachusetts Institute of Technology
RSM	Response Surface Methodology
PE	Polyethylene
PVC	Poly Venyl Chloride
PS	Polystyrene
SEM	Scanninigg Electromicroscopy
TGA	Thermogravimetric Analysis
USCS	Unified Soil Classification System
USDA	U.S. Department of Agriculture
XRD	X-Ray Diffractometry
W	Weight
K	Scherrer constant
t	Thickness
σ	Flexural strength

ABSTRACT

These days, plastic wastes are the major environmental concerns that need rapid and continuous solution. These wastes have to be either recycled or converted to less harmful products. Apart from this, construction industry is growing with booming rate with high demand of construction materials. This thesis work is aimed to utilize plastic wastes of high density polyethylene as binding agent in the production of terrazzo tiles for out door applications. The significance of this study is that it can be used as input for policy makers and for future researchers around the topic. The production steps include: raw materials preparation, melting the plastic wastes, mixing molten plastic and sieved river sand and molding using hydraulic pressing machine. The single and the interaction effects of three process variables (percentage of plastic waste, sand particle size and pressing pressure) on the flexural strength of the terrazzo tiles were analyzed and discussed. The produced terrazzo tiles were analyzed for their physico-mechanical characteristics such as flexural strength, water absorption and surface morphology. The maximum bending strength of 20.7MPa was obtaianed at the optimum process variables (pressing pressure of 6MPa, plastic composition of 40% and sand particle size of 0.61mm). The maximum and the average water absorption of the tiles were 0.28% and 0.11% respectively. The pruduced terrazzo tiles have light weight but better physico-mechanical properties compared to conventional terrazzo tiles. These are good indicatives that show the produced terrazzo tiles can fit for the planned out door paving applications. Since the required properties are in the commonly exprienced range, it can be concluded that high density polyethylene plastic wastes can be used for the production of terrazzo tiles in the presence of the reinforcing river sand. Here, the plastic waste was used for binding purpose and it can be potential substitution for cement in the production of composite terrazzo tiles.

Key words

Plastic waste, terrazzo tiles, high density polyethylene, river sand, flexural strength, physico-mechanical characteristics.

1.INTRODUCTION

Plastic wastes from used plastic products are one of recent environmental concerns that require indispensable solution. Plastic products are used almost everywhere on the earth. There are different types of plastics, the common one are thermoplastics and thermoset plastics. Thermoset plastics cannot be re-molded after ones made. But thermoplastics can be re-shaped and reprocessed many times into different shapes upon the application of heat. Polyethylene is one of thermoplastics. Based on density, polyethylene is categorized into low density polyethylene(LDPE) and high density polyethylene(HDPE).

This thesis work is considered high density polyethylene. HDPE is tougher and stiffer than LDPE and is always milky white in color, even when very thin. High density polyethylene is used in many applications such as bags and industrial wrappings, soft drinks bottles, detergents and cosmetics containers, toys, jerry cans, crates, dust bins, and other household articles(Ampofo, 2009). The waste plastics alone or blended with other materials can be used in production of various profiles such as roof tiles, floor tiles, pavement tiles, wall tiles, draining canal, boutique shopping toys, park benches, fences, poles and the like based on the proportion of raw materials and the required properties of the final products(Guendouz et al., 2016).

Apart from the above, construction industry is increasing with increasing number of puplation in the earth planet. This results in the higher demand of various types of construction materials. Woods, stones, metals, tiles, cement and binders are some of those construction matrials used as input for construction industries. This study focuses on utilization of HDPE plastic wastes as a binder for production of terrazzo tiles by blending it with river sand.

Production of tiles from such materials may have various advantages. It may provide the combined effect of its ingredients, it may give an interesting aesthetic value, it will not generate much dust on paving, it may be lighter than cement and concret tiles, it may give moderately durable and environmentally safe material, it may reduce costs for cement.

1.1 Statement of the Problem

These days, plastic products are used almost everywhere on our planet and become waste after their usage. Most of the wastes from these plastics are not easily decomposed. In stead, they are simply dumped in landfills and stay long. High density polyethylene is one of the plastics mainly used and found in the plastic wastes. According to the Olumuyiwa study, 67,235 tonne of plastics have been annually imported by Ethiopia(Olumuyiwa, 2001). From this, 40.58% or 27,283.8 tonne was polyethylene and the related. The carelessly discarded wastes of these plastics are choking animals, spoils soils, plants, and blocks water way and kills animals when being fed. Generally, plastic waste has already become a serious environmental problem in Africa in general and in Ethiopia in particular. There are many types of plastic utilization techniques such as depolymerization, incerination, gasification, degradation through radiation. However, the above techniques are conducted at higher temperature and consume large amount of energy(Clough, 2000). Apart from the above, it is possible to reutilize plastic wastes into useful products with relatively low energy consumption and with simpler processing.

In another way, construction industries are growing with booming rate following the alarming population growth rate. Terrazzo tiles are one of the construction materials highly demanded and consumed in construction sector. Most of these tiles are produced from raw materials such as sand, cement, clay, marble and other additives. They are made into large thickness and weight. This result in higer consumption of raw materials such as cement, sand and become consequence for high cost of production. Apart from this, terrazzo tiles produced from such materials are easily broken and cracked upon the exposure to the impact and the bending forces. This study aims to re-utilize wastes from HDPE plastic wastes in the production of valuable, light weght ***terrazzo tiles*** with better physio-mechanical characteristics.

1.2 Objectives of the study

1.2.1 General objective

The general objective of this thesis work is to utilize high density polyethylene wastes as binding agent for the production of *terrazzo tiles* in the presence of reinforcing river sand.

1.2.2 Specific objectives

The specific objectives of this research are:

- To characterize the river sand for its moisture content, bulk density and crystallinity.
- To characterize HDPE plastic waste for its bulk density and thermal properties.
- To develop product(terrazzo tiles) from HDPE plastic waste and river sand
- To determine optimal operating variables (HDPE waste to river sand blending composition, sand particle size, pressing pressure) required for production of terrazzo tiles with the best flexural strength.
- To characterize physico-mechanical properties (water absorption, surface morphology and flexural strength) of the produced terrazzo tiles.

1.3 Significance of the study

Significance of this study is that to show the possibility using HDPE waste as binding agent for production of terrazzo tiles. The study can also be used as starting point for further researches to reutilize HDPE waste in construction industries. It can also be an input for policy makers in area of plastic waste utilization.

If this study is successfully converted to actual production at industrial level, it will have many fold benefits both for producers and for the local community. It has potential environmental, economical and social advantages. First, it will minimize plastic wastes, their environmental effects and cost to treat them. Second, it produces value added products which can substitute construction materials like marble and cement tiles. It also creates job opportunity for those who collect and sell the wastes. Generally, it is useful to enhance cleaner urban cities, reduce blockage of urban drainage systems clogged by plastic waste and promote job creation in the recycling process.

1.4 Scope of the Study

This thesis work covered raw material collection for production of terrazzo tiles from the blended plastic waste and river sand using cold hydraulic pressing method. In the process, the raw materials were characterized and physico-mechanical properties (water absorption test, flexural strength test and surface morphology) of the final product were charecterized and compared to the standards. The effect of temperature, cooling rate and molecular weight were not analyzed due to the lack of testing tools. Abrasion resistant and fire resistance test were also jumped due to un availability of testing machines.

2. LITERATURE REVIEW

2.1 Plastics and Their Properties

Plastics are man-made organic materials that are produced from oil and natural gas as raw materials. Plastics can be regarded as long chains of beads in which the so called monomers such as ethylene, propylene, styrene and vinyl chloride are linked together to form a chain called a polymer. Polymers such as polyethylene (PE), polystyrene (PS) and polyvinyl chloride (PVC) are the end products of the process of polymerization, in which the monomers are joined together. In many cases only one type of monomer is used to make the material, sometimes two or more. A wide range of products can be made by melting the basic plastic material in the form of pellets or powder(Ampofo, 2009).

Plastic product importation and production are high in the world. Ethiopia is also one of the countries which import and use plastics. According to the Olumuyiwa study, 67,235 tonne of plastics have been annually imported by Ethiopia(Olumuyiwa, 2001). From this, 40.58% or 27,283.8 tonne was polyethylene and the related. The data is shown in the Table 1. From the table, it is observed that the amount of imported plastic is increasing year to year. By their nature plastics are not easily decomposed after their usage. So they need to be recycled or reutilized into valuable products.

Table 1: The Import of plastic resins in Ethiopia

Type/ Year	2009	2010	2011	Average	% share
Polyethylene and related	27,006.1	27,006.1	27,839.1	27,283.8	40.58
Polypropylene and related	9,270.3	13,071.0	16,955.7	13,099.0	19.48
Polyvinyl chloride and related	14,836.3	9,251.2	8,928.2	11,005.2	16.37
Ethylene-vinyl acetate and related	5,484.7	5,647.7	7,990.2	6,374.2	9.48
Other polyethers	3,042.2	2,454.9	2,447.8	2,648.3	3.94
POLY(ETHYLENE TEREPHTHALATE)	1,215.0	1,971.3	4,081.5	2,422.6	3.60
polyesters	828.7	1,152.7	1,143.9	1,041.7	1.55
Polymers of halogenated olefins	935.3	491.4	944.6	790.4	1.18
Alkyd resins	446.1	555.5	1,154.5	718.7	1.07
Polystyrene and related polymers	29.0	1,152.7	349.2	510.3	0.76
Acrylic	1,011.7	156.8	292.6	487.1	0.72
Polyamides	167.0	980.4	130.3	425.9	0.63
Epoxide resins	343.2	12.6	887.5	414.4	0.62
Polycarbonates	5.5	0.3	16.7	7.5	0.01
POLY(METHYL METHACRYLATE)	0.6	5.9	10.7	5.8	0.01
Total	64,622	63,911	73,172	67,235	**100**

Source:(Olumuyiwa, 2001)

2.1.1 Types of Plastics and Variation in Their Property

Plastics can be either thermoplastics or thermosets. Materials that repeatedly soften on heating and harden on cooling are known as thermoplastics. thermoplastics can be melted down and made into new plastic end products. They are dense and hard at room temperature, become soft and moldable when heated, dense and hard again and retain new shapes when cooled. This process can be repeated numerous times and the chemical characteristics of the material do not change. Examples of thermoplastics are: polyethylene, poly propylene, polystyrene, poly vinyl chloride. Symbols or codes used to identify some of plastic types are shown in the Figure 1.

The second type of plastic material is thermoset. Thermoset plastics are not suitable for repeated heat treatments because of their complex molecular structures. The structure of thermosetting materials resembles a kind of thinly meshed network that is formed during the initial production phase. Such materials cannot be reprocessed into new products unlike thermoplastics. Thermosets are widely used in electronics and automotive products. Thermoset plastics contain alkyd, epoxy, ester, melamine formaldehyde, phenolic formaldehyde, silicon, urea formaldehyde, polyurethane, metalised and multilayer plastics etc(UNEP, 2009). The properties of plastics can be modified by a number of substances known as additives.

Symbols	Description	Commonly found in
1 PETE	Polyethylene Terephthalate	Soda, water, and beer bottles; salad dressing containers
2 HDPE	High Density Polyethylene	Milk jugs; household cleaner containers; juice bottles; yogurt tubs
3 V	Vinyl	Shampoo bottles; cooking oil bottles; medical equipment; piping
4 LDPE	Low Density Polyethylene	Squeezable bottles; shopping bags; carpet; frozen food; food wraps
5 PP	Polypropylene	Yogurt containers; ketchup bottles; syrup bottles; medicine bottles
6 PS	Polystyrene	Meta trays; egg cartons; disposable plates and cups
7 OTHER	Miscellaneous	Sunglasses; iPod cases; computer cases; bullet-proof materials

Figure 1: Symbols used to identify types of plastics

2.1.2 Polyethylene Plastics and their Properties

Polyethylene is one of thermoplastic polymer materials. The solid form of polyethylene was created by British chemists Eric Fawcett and Reginald Gibson in 1935. Its first commercial application came during World War II, when the British used it to insulate radar cables. High-density polyethylene (HDPE) was invented in 1953 by Karl Ziegler of the Kaiser Wilhelm Institute and Erhard Holzkamp (Gabriel, 1998).

There are three common types of polyethylene. These are high density polyethylene (HDPE), low-density polyethylene (LDPE) and linear low density polyethylene(LLDPE). LDPE is soft, flexible and easy to cut, with the feel of candle wax. When very thin it is transparent, when thick it is milky white, unless a pigment is added. The third type of polyethylene is linear low density polyethylene (LLDPE). It consists linear polyethylene with branches of short length (2-8 CH2 units). It is produced by copolymerization of ethylene with butene, hexene, or octene. A schematic illustration of the three various polyethylene was depicted in the Figure 2.

HDPE is tougher and stiffer than LDPE and LLDPE. It is always milky white in color, even when it is very thin. The range of plastic containers and other products made with HDPE resins are vast. Examples are liquid food bottles (e.g. milk containers); containers for household cleaning products, pharmaceuticals, bags and industrial wrappings and personal-care products; industrial drums and buckets; fuel tanks; truck bed-liners; housewares; toys; sporting goods; and pipe and conduit, toys, jerry cans, crates, dust bins, T-shirt sacks and plastic grocery sacks, bakery bags, carton and box liners, cereal and cake mix bags, shipping sacks, industrial liners, retail bags, grocery sacks and other household articles(Ampofo, 2009).

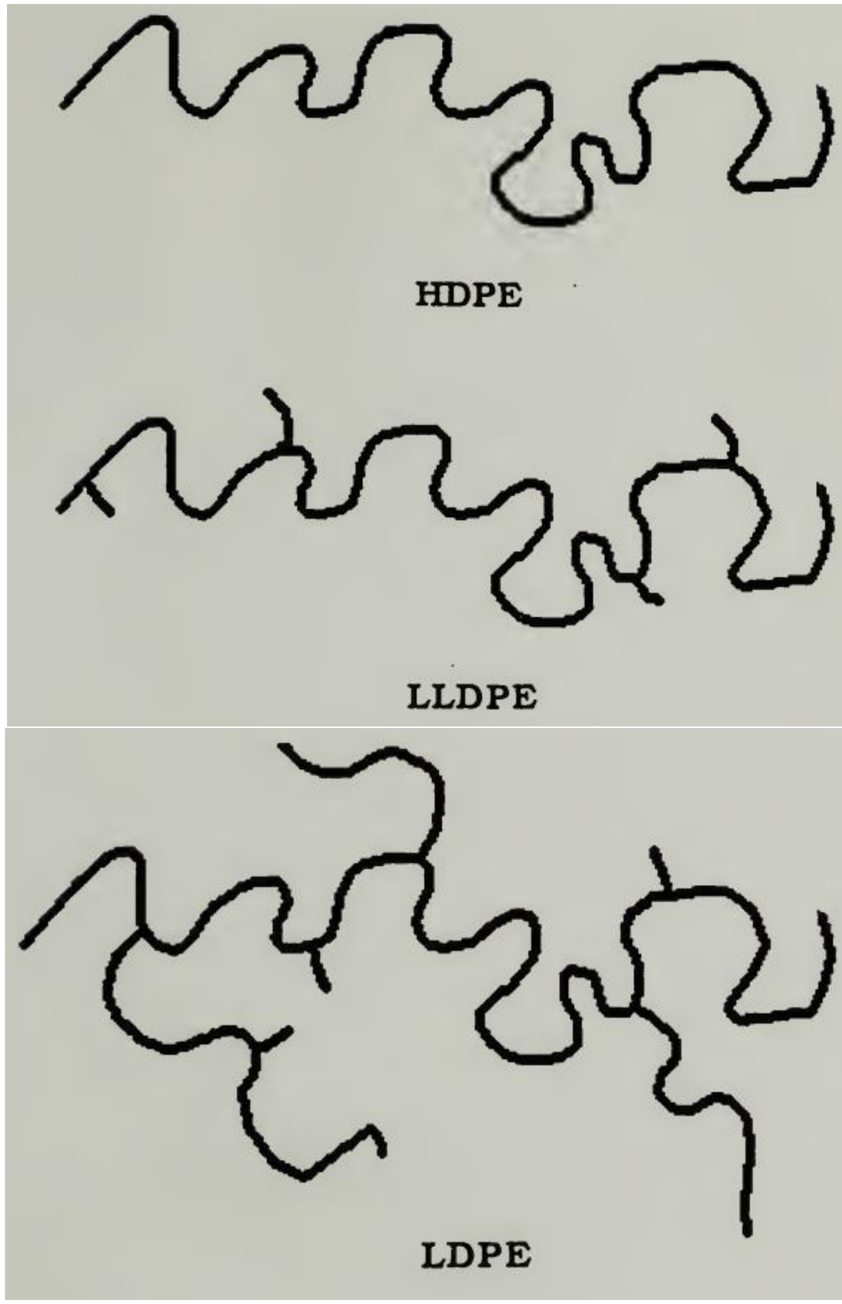


Figure 2: A schematic illustration of various polyethylene

Source: University of Massachusetts Amherst(Schultz, 2010)

2.2.2.1 Properties of High Density Polyethelyne

High-density polyethylene is a thermoplastic material composed of carbon and hydrogen atoms joined together forming high molecular weight products as shown in Figure 3(a). Its density is ranging from 0.941 to 0.965 g/cm^3(Schultz, 2010). HDPE tends to be stiffer than other polyethylene films, which is an important characteristic for packages that need to maintain their shape. In addition, HDPE is strong and rupture resistant. It has good moisture barrier properties and is resistant to grease and oils(Testin & Vergano, 1997). As shown in Figure 3 (b) and (c). It is primarily linear in structure with few side branches (less than one side chain per 200 CH2 units). HDPE is highly crystalline, with crystallinities as much as 90% by volume. It has good tensile strength and hardness. This enable it to be used in bottles, conduits and many other containers(Schultz, 2010).

In HDPE and other thermoplastic materials, the molecular chains are not cross-linked and such plastics will melt with the application of a sufficient amount of heat. With the application of heat, thermoplastic resins may be shaped, formed, molded or extruded.

High density polyethylene has the following chemical structure and arrengements.

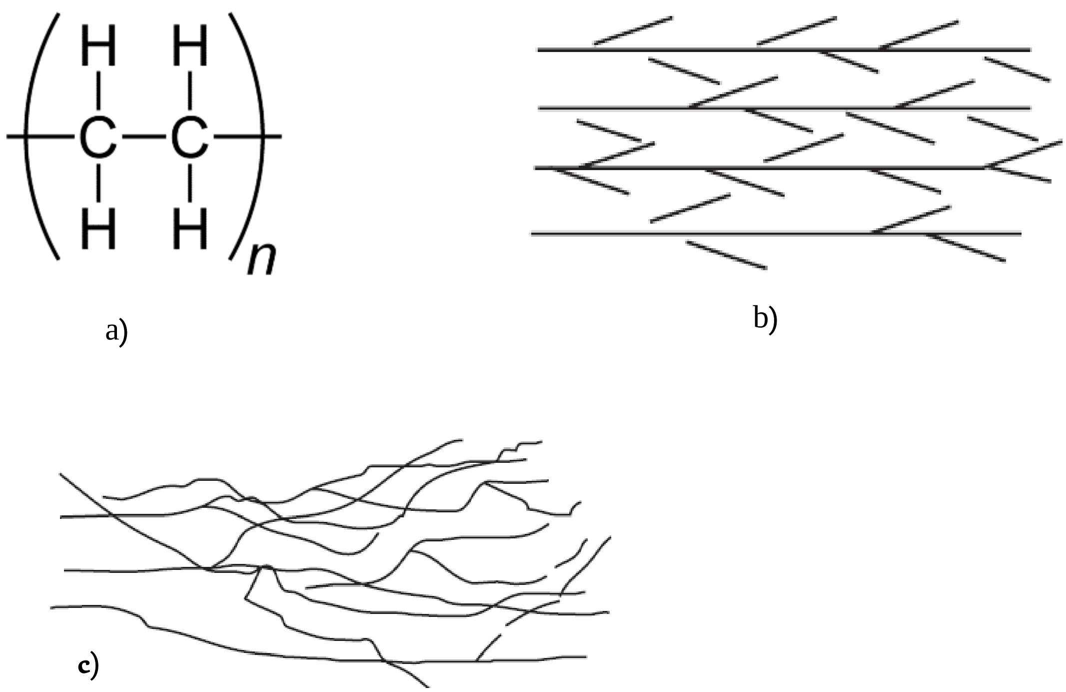


Figure 3: a) Structural formula, b)Linear, c) Branched arrangement of HDPE

Source: History and Physical Chemistry of HDPE(Gabriel, 1998)

2.1.3 Methods to Investigate Thermal Properties of Plastics

Thermal properties of plastic materials are mostly determined by employing the techniques such as thermogravimetry and differential scanning calorimetry.

2.1.3.1 Thermogravimetry(TGA)

Thermogravimetry (TG) is the branch of thermal analysis which examines the mass change of a sample as a function of temperature in the scanning mode or as a function of time in the isothermal mode. Not all thermal events bring about a change in the mass of the sample (for example melting, crystallization or glass transition), but there are some very important exceptions which include desorption, absorption, sublimation, vaporization, oxidation, reduction and decomposition. TG is used to characterize the decomposition and thermal stability of materials under a variety of conditions and to examine the kinetics of the physicochemical processes occurring in the sample. The mass change characteristics of a material are strongly dependent on the experimental conditions employed. Factors such as sample mass, volume and physical form, the shape and nature of the sample holder, the nature and pressure of the atmosphere in the sample chamber and the scanning rate all have important influences on the characteristics of the recorded TG curve.

TG curves are normally plotted with the mass change (Δm) expressed as a percentage on the vertical axis and temperature (T) or time (t) on the horizontal axis. The reaction is characterized by two temperatures, Ti and Tf , which are called the procedural decomposition temperature and the final temperature, respectively. Ti merely represents the lowest temperature at which the onset of a mass change can be detected for a given set of experimental conditions. Similarly, Tf represents the lowest temperature by which the process responsible for the mass change has been completed. The values of Ti and Tf have no absolute significance as both the reaction temperature and the reaction interval (Ti - Tf) have no definitive value but depend on the experimental conditions(Hatakeyama & Quinn, 1999).

2.1.3.2 Diffrential Scanning Calorimetery

Diffrential scanning calorimeter is a techniques used to determine thermal properties of plastic such as melting and decomposition temperatures. It is a thermal analysis technique which measures the temperature and heat flow associated with transitions in materials as a function of temperature and time. Such measurements provide quantitative and qualitative information about physical and chemical changes that include endothermic/exothermic processes or changes in heat capacity. Specific information that can be obtained include: Glass transition temperatures, melting points & boiling points, crystallization time & temperature, percent crystallinity, heats of fusion and reaction, specific heat, oxidative stability, rate of cure, degree of cure, reaction kinetics, purity, thermal stability(Taylor, 1962).

2.2 Plastic Wastes and Its Environmental Impacts

These days, plastic wastes are everywhere on the world. The Plastic Waste component of the Municipal Solid Waste is quite problematic because they are non-biodegradable and therefore can stay in the environment for a considerable length of time causing all sorts of problems. As they are not rapidly decomposable, they pollute soil, water, river, block water way and rain to penetrate into soil(Ampofo, 2009). The management of Plastic Wastes by process such as chemical recycling, combustion, incineration and gasification are not environmentally friendly and sustainable since this may release gases such as carbon dioxide which are major contributor to greenhouse effect.

Landfilling with Plastic Waste is not also desirable since plastic is non- degradable and no economic value would have been derived from the waste in that case. The best option for Sustainable Plastic Waste Management is through physical and mechanical recycling and reutilizing of them into valuable produccts(Sawitri, 2011). This is because the benefits of re-utilizing of Plastic Waste are numerous and also environmentally friendly compared to the other methods of waste disposal. Through recycling of Plastic Waste into useful products, we can have material and energy recovery and therefore value will be derived from the waste instead of regarding it as rubbish(Wienaah, 2007). Recycling is chosen because it has numerous advantages over the other modes of waste disposal and comparatively less capital intensive.

Literature information for this study was gathered from diverse sources. These include information gathered through the internet from different sources such as journals, technical reports on international research work on plastic waste recycling, press releases on recycling and findings of research centers and pilot projects. Other sources of information included key informant interviews and field visits to local plastic industries.

In order to recycle plastic wastes into valuable products, understanding the plastic definition, its source, type and its properties are very important.

2.3 River Sands

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. Sand is typically made up of Quartz (SiO2). It can in fact be composed of almost any mineral or combination of minerals or even sand sized fragments of rocks. The source rock and weathering and transportation history of sand usually results in a particle size distribution that can be characteristic of a sample. Sands from these different sources are washed and taken by the rain water and deposited along side of rivers. From this deposited sources, the sand got the name 'River Sand'. Sands are mainly used in construction sectors. Its application is vital in the production of asphalt, concret, beams, bricks, tiles etc. some literature suggests that sand used in tiles production has to be well graduated and free of any organic matter and soil(States, 2008). According to AASHTO, the differences between aggregate(gravel), sand, silt and clay are depicted in the Table 2. Some previous study(Karam & Tabbara, 2009; Umass, 2013) suggested river sand of particle size between 0.1mm and 2.0mm for production of terrazzo tiles from Portland cement.

Table 2: Soil Classification Basics

Soil Type	USCS Symbol	Grain Size Range (mm)			
		USCS	AASHTO	USDA	MIT
Gravel	G	76.2 to 4.75	76.2 to 2	>2	>2
Sand	S	4.75 to 0.075	2 to 0.075	2 to 0.05	2 to 0.06
Silt	M	Fines < 0.075	0.075 to 0.002	0.05 to 0.002	0.06 to 0.002
Clay	C		< 0.002	< 0.002	< 0.002

Source:(Umass, 2013)

2.4 Terrazzo Tiles

According to European and British standard definition, tiles are slab made from sands and other inorganic raw materials. They are generally used as coverings for floors and walls. They are usually shaped by extruding or dry-pressing methods at room temperature followed by drying and firing at temperatures sufficient to develop the required properties. Apart from the above, tiles can be formed by other processes. Tiles can be glazed or unglazed and are incombustible at low temperature and unaffected by light(Delhi, 1998). There are different types of tiles. These include: terrazzo tiles, ceramic tiles, concrete tiles, mosaic tiles, composite tiles. Previously, tiles were made from, cement and sand, clay and sand, cramic or composite materials. The raw materials used in this study were plastic wastes with HDPE basis and river sand.

Terrazzo is a word derived from the Italian to designate any mosaic flooring made by embedding small pieces of marble or colored stone in mortar followed by polishing the surface. The terrazzo is typically used as a finish for floors, stairs or walls. The common terrazzo tile is composed of two bonded layers, the upper one having a smooth surface and constituted of cement, usually white cement, mixed with predetermined amounts of marble chips or other hard stone, and of powdered stone or marble. The lower layer shall be constituted of ordinary Portland cement, sand, and aggregate mostly between 0.1mm and 2.0mm in size(Karam & Tabbara, 2009).

Nowadays, reinforced plastic composites are introduced and replacing cement which are being used for many years. This is due to the fact that reinforced plastics have high strength to weight ratio, low cost compared to marble and cement, and high resistance to corrosion. However, the production of the composites nowadays is very challenging to meet the market requirement. The reinforcements may vary according to the desired function of the composite. Many composites have been produced using fibers (short and long), and particles as reinforcements. However, though natural sand is abundant in the world and very cheap, there are no many studies regarding the mechanical properties of natural sand particle reinforced composites. The composite produced thus has to be tested for its mechanical properties before being used as replacement to cement, concrete or marble(Guendouz et al., 2016). To summarize, composite materials are multiphase materials obtained by artificial combination of different materials to attain properties that the individual components cannot attain.

2.5 The Conventional Tiles Production Methods

Terrazzo tiles are suitably compacted elements of uniform shape and thickness, which conform with the standard. The tiles may be single or dual layered. They are either individually produced by compression and/or vibration and/or vacuum before being cut to size(BS EN, 2004). Pre-cast terrazzo tiles are widely used as floorings in the Mediterranean countries, the Middle East and parts of America and Asia, in residential, commercial, and institutional buildings. Tiles are manufactured in sizes varying typically from 10 cm x 10 cm up to 40 cm x 40 cm. the common production process include mechanical vibrating in the mold, hydraulic pressing, curing in water or air and polishing before shipping to site. Final polishing is performed in situ after setting and leveling the pre-cast tiles on a sand bed(Karam & Tabbara, 2009).

The common production process of composites from various plastic wastes and reinforcement fillers involve raw material collection, sorting, cleaning, size reduction, melting of the plastics, blending and pressing. The product is then cooled, trimmed and dried.

a) Sorting of the Plastic Wastes

When recycling plastics it is essential that the materials are correctly identified. If not, this can create several problems during reprocessing, leading to products with a poor appearance and impaired mechanical properties. It is usually difficult to tell exactly which type of plastic is present solely from the type of product. Many different types of plastics may look identical, or one type of plastic may appear to have several physical and chemical characteristics depending on the type of additive that has been used(Konin, 2011). Detailed chemical tests, such as FTIR, TGA and DSC analysis, may be needed to make a definite identification of a polymer. Some simple tests using basic equipment can provide important information for identification. In Istanbul, for example, some re-processors claim to be able to distinguish plastics by touch, but when in doubt, they apply the "burning test" or the "flotation test(Ampofo, 2009). Some plastic polymer products are fabricated with recycling identification codeas shown in Figure 1.

b) Cleaning of the HDPE Wastes

Plastic waste may have different types of dirties as they were used for different purposes. Some of them may be used as containers of oils, lubricants, chemicals and cosmotics. They can also be in contact with soil or other wastes when disposed after their usage. So, they have to be properly washed before recycling processes. To wash them different types of detergents and soaps can be used as required.

c) Size Reduction of the HDPE Wastes

To make it easy for cleaning and melting, plastic wastes collected from different waste disposal areas has to be reduced into the required size using size reducing or sherdding machines(Arora, 2013). The size reducing equipment such as shredder and crusher can be used to reduce the size of the plastics as shown in the following Figure 4**.**

Figure 4: Grinding of various plastic wastes

Source:International Journal of Students Research in Technology & Management Vol 1 (04), August 2013

d) Melting of plastic waste

The waste is crushed in order to facilitate the cast and placed in a drum where they are heated. Melting of plastic waste and progressive addition of reinforcing fillers have to be combined and mixed vigorously in order to make the blend homogeneous. The melting temperature depends on the plastic type. P. Herrera-Franco and his coworkers was used the processing temperature of 160, 170 and 180°C for HDPE and sand composite (Yucatan & Postal, 1997). According to this study, temperatue at 170°C gives a composite with better flexural strength.

e) Mixing of Melted Plastic and River Sand

The melted and liquefied plastic wastes are mixed wih the fillers while stirring the mixture so that it may be homogeneous. Some study have reported that when some percentage of plastic waste such as PET are used as a binder to produce polymer concrete, they gave a material with better compressive and flexural strength than cement Portland concret. In any case, their results showed that the inclusion of plastic waste eliminates the shrinkage cracking of concrete and reduces the drying shrinkage to some extent(Journal, Engineering, 2017).

f) Forming of the TerrazzoTile

Most tiles are formed by dry pressing. In such method, the free flowing powder containing organic binder or a low percentage of moisture flows from a hopper into the forming die. The melted plastic is then mixed with the grinded sand and transferred to mold fixed with pressing machine(Bagnara & Vic, 2009). The pressing process is done immediately after melting and blending as much as possible. The blend in the mold is hydraulically pressed to the required pressure for 13 minutes as mentioned by Tabbara(Karam & Tabbara, 2009).

Several other methods are also used where the tile body is in a wetter, more moldable form. Extrusion plus punching is used to produce irregularly shaped tile and thinner tile faster and more economically. This involves compacting a plastic mass in a high-pressure cylinder and forcing the material to flow out of the cylinder into short slugs. These slugs are then punched into one or more tiles using hydraulic or pneumatic punching presses. Ram pressing is another tile forming method often used for heavily profiled tiles. With this method, extruded slugs of the tile body are pressed between two halves of a hard or porous mold mounted in a hydraulic press.

The formed part is removed by first applying vacuum to the top half of the mold to free the part from the bottom half, followed by forcing air through the top half to free the top part(Saravanan et al., 2017). Excess material must be removed from the part and additional finishing may be needed.

Another process, called pressure glazing, has recently been developed. This process combines glazing and shaping simultaneously by pressing the glaze (in spray-dried powder form) directly in the die filled with the tile body powder. Advantages include the elimination of glazing lines, as well as the glazing waste material (called sludge) that is produced with the conventional method(Adeola. al, 2015). Most tiles are formed by dry pressing. In such method, the free flowing powder containing organic binder or a low percentage of moisture flows from a hopper into the forming die.

The mold is first coated with vegetable fat to facilitate the withdrawing of tile from it. It should be spread out so as to cover the entire mold. The produced tile is discharged out of the mold by pushing up the metal sheet supporting the tile using the whole designed beneath the mold. This operation must be carried out before the cooling of the mixture.

g) Cooling and Drying of the Product

After formation of tile in the mold, the mold is placed in a basin containing water till the cooling of the mold which allows obtaining a rigid tile with plastic as a binding material. The composite tile usually must be dried after forming, especially if a wet method is used. Drying, which can take several days, removes the water at a slow enough rate to prevent shrinkage cracks. Continuous or tunnel driers are used that are heated using gas or oil, infrared lamps, or microwave energy. Infrared drying is better suited for thin tile, whereas microwave drying works better for thicker tile. Another method, impulse drying, uses pulses of hot air flowing in the transverse direction instead of continuously in the material flow direction(Fini et al, 2013)

2.5.1 Application of Composite Tiles

Composite tiles can make a variety of building materials that are cheaper than the concrete version. They set quickly and are very strong. Depending on the mould, it can be made into floor or paving tiles or even bricks for walls. They also make good rain water harvesters: being nonwater absorbent, the risk of dew, algae and fungus is almost eliminated, and this ensures clean water. Bricks made with this technique make good insulation, keeping home warm in winter and cool in summer. The sand in the tiles acts as a fire retardant. If there is a fire, the outer layer of plastic melts, leaving a face of sand. Sand is not flammable, so it slows the spread of the fire through the brick. Hohever, plastic tiles are not advisable for roofing in case of fire(Wienaah, 2007).

3. MATERIALS AND METHODS

3.1 Equipment and Tests Required

For the production and characterization of terrazzo tiles from HDPE plastic waste and river sand, the main equipment used were: hydraulic press to mold the tiles, thermometer to measure temprature during melting, size analyzing sieve, analytical balance, desiccator used to store samples in a moisture-free environment, drying chamber (oven), FTIR, XRD, TGA, heating mantle, melting drum, wooden stirrer, molder, grinder, tong, scissor, safety equipment(eye glass or goggle, leather glove, face mask), Aluminum foil, flexural strength testing machine and scanning electron microscope (SEM) for micro structure and surface morhophology test.

3.2 Raw Materials Collection and Pretreatment

For the manufacture of terrazzo tiles, the main raw materials used were HDPE plastic wastes and river sand.

3.2.1 Plastic wastes

Plastic wastes used were mainly from packaging and other elements with a basis of High Density Polyethylene (HDPE). These plastic wastes were collected from waste disposal areas of Addis Ababa city specially from AAiT and collage of natural science compound. HDPE plastic waste was isolated from other plastic wastes by their codes on the plastic products. According to these codes, HDPE is given number **2** in a triangle as shown in Figure 1. To minimize effects due to various molecular weight and variability in melting temperature of the plastic wastes, the wastes from the same origins were used as much as possible. Normally, plastic wastes have to be shredded into small flakes before melting (Arora, 2013). But the availability of plastic shredder is less in Ethiopia. For this reason, the author used water bottles' lids' of HDPE origin. This is because the lids size is small and easy for melting without the requirement of shredding machine**.**

Plastic wastes might be come in contact with different wastes and might be come from different application areas such as motor oil containers, industrial wrappings, soft drinks bottles, detergents and cosmetics containers, toys, jerry cans, crates, dust bins, milk containers, bleaching bottles or they may be in contact with other wastes at waste disposal. So it has to be washed accordingly. Here, the plastic wastes were washed by using tap water and detergents until dirties on them were cleaned well. This is done inorder to reduce the effects of impurity due to dirties on the production process and on the final product.

3.2.2 River Sands

The sand used in this study was collected from lowland area found in Sawenna District of Bale Zone, Oromia Regional state. The specific place is known as 'Charchel', which is found at 635 km south East from Addis Ababa. Of all types of reinforcements, natural river sand were selected for this study because of their availbility, less silt content and and ability to produce hard terrozzo tiles with better strengths relative to other reinforcements. The rivers from where the sand collected are called "Dharae and Chalchal rivers." The sand was prepared into different sizes by sieving analysis without requiring further size reduction. The sand is also found in Dello Menna, Adaba-Dodola, Matahara and Meki. Currently, the sand is used to make concret for different construction application.

To clean soil out of them, sands can be washed using tap water before using them. Since it has less silt content, sand for this thesis work was used directly without the need of washing. After collection, the sand was sieved and prepared into particles sizes of 0.375, 0.605 and 0.855mm following the sieve analysis techniques. The above river sand particle sizes were arranged by taking some previous researchers reports as reference point (Umass, 2013; Karam & Tabbara, 2009). The sieve analysis technique and calculation is explained under appendix A.

Figure 5: Raw materials a) sand, b) HDPE waste(water bottles' lid)

3.3 Characterization of Raw Materials and Terrazzo Tiles

To conduct this study the following methods have been used. These include determination of moisture content and bulk density of the raw materials; HDPE plastic waste and river sand following using ASTM C 566 and ASTM C 29 respectively. Determination of crystallinity of salt by using XRD. Analyzing of thermal properties of plastic waste using DSC and TGA techniques. Functional group existing in the sand, plastic waste and tile was analysed by FTIR. Product was developed (terrozzo tiles from HDPE wastes and river sand) following melting, blending and molding method. All these methods were discussed in details in the next section.

3.3.1 Moisture Content of River Sand

Moisture content of the sand was perfomed to check whether it is required or not to dry the sand before mixing with the melted plastic. The collected river sand was dried by sun in open air for half day by turning right and left in 1hour intervals. This was done to remove surface water and moisture of river sand inoreder to facilitate it for the consecutive processes. To conduct the moisture content test, the weight of four samples of the sun dried sand was taken at room temperature and after heating in an oven at 105 ^{0}C overnight. The results were tabulated in the appendix F. The moisture content was then abtained from the average of weight difference on wet basis. Sample was measured and taken in a petridish. It was dispersed nicely on the petri dish. It was then heated at 105°C for 12hr. The petri-dish was left open during the heating process. After heating, the petri-dish was cooled in desiccator and then weighed. This specifies the amount of moisture content present in the sample.

$$\boldsymbol{Moisture}, \% = \frac{\boldsymbol{W_1 - W_2}}{\boldsymbol{W_1}} * \mathbf{100} - - - - - - - - - - - - - - \quad (1)$$

Where: W_1 = weight of sample and petri dish before drying (gram).

W_2 = weight of sample and petri dish after drying (gram).

3.3.2 Determination of Bulk Density of Sand and HDPE Plastic Wastes

Density of the sand and the HDPE were determined by displacement method using pychnometer and distilled water(at 20^{o}C and 1atm). First, weight of empty pychnometer with its cover was measured. Then, almost half of the pychnometer was filled with the sample and its weight was taken. Next, the rest of the pychnometer space was filled with distilled water and its weight was taken again. Here, density of the distilled water is taken to be 1 g/cm^3. Density of the sample was then calculated as follow.

$$\textbf{Bulk density of sample} = \frac{\boldsymbol{mass\ of\ sample}}{\textbf{volume of sample}} \quad - - - - - - \quad (2)$$

3.3.3 X-ray Diffraction (XRD) Spectroscopy

The X-ray diffraction pattern is a fingerprint that figure out what is in the particular sample whether it is crystal or amorphous. The diffraction pattern of a mixture is a simple sum of the diffraction pattern of each individual phase(Taylor, 1962). In this study, XRD analysis is used to check crystallinity of the sand. This analysis is one of the most commonly used techniques for either crystalline or amorphous phase identification. In this technique, the catalyst sample is irradiated with X-ray of a known wavelength (λ). The X-ray diffraction (XRD) patterns of sand powder were obtained using MiniFlex 300/600, Japanoperated at 40 kV and 15 mA, using Ni-filtered Cu-Ka radiation (1.54059-1.54441). The samples were placed on a sample holder made up of silicon wafer and the measurements were taken continuously from 10^{o} to 80^{o}angles over the range of 2θ. The resultant intensity data was processed by using origin pro software to graph and analyze the peak position. A custom-made sample holder with a shallow well was used for the samples, and rotated to improve particle statistics. These analyses have been performed in Addis Ababa University, college of natural science in the department of chemistry.

3.3.4 Fourier Transorm Infrared Spectroscopy

In physical and analytical chemistry, infrared spectroscopy (IR spectroscopy) is a technique used to identify chemical compounds based on the way infrared radiation is absorbed by or transmitted thruogh the compound(Pagès, 2005). Here, the FTIR measurement was conducted to characterize the raw materials(sand and plastic) and the product by functional group identification. This helps to predict the interaction of plastic waste and sand in the product matrix.

The chemical compositions of plastic waste and sand were determined using FT-IR spectroscopy (FTIR-65, Perkin-Elmer) with the more conventional KBr technique. FT-IR spectroscopy is an important method to determine the presence and absence of particular bands of functional groups. FTIR is most useful for identifying chemicals that are either organic or inorganic. The instrument used was able to record spectra from wave numbers of 4000 to 400 cm^{-1}. Spectrum is produced as a result of the absorption of infrared radiation.

The functioning group is determined based on the interpretation of the infrared spectrum obtained by comparing it with the standard spectrum group frequencies. The sieved sand, the grinded HDPE and terrazzo tiles were first separately milled in ceramic pestle and mortar to powdery condition. The powder was then pressed to a small thickness, slightly below 1mm, required for FTIR analysis. FTIR Analysis was conducted in Addis Ababa University at college of natural science in the department of chemistry. The FTIR data was drown into graph by using origin pro 8.0 and shown by figure13.

3.3.5 Characterization of Thermal Properties of Plastic Waste

To determine thermal propeties of the raw material and that of the product, diffrential scanning calorimery and thermogravimetric analysis was used.

3.3.5.1 Diffrential Scanning Calorimery

Differential scanning calorimetry (DSC) is a thermal analysis technique which measures the temperature and heat flow associated with transitions in materials as a function of temperature and time. Such measurements provide quantitative and qualitative information about physical and chemical changes that include endothermic/exothermic processes or changes in heat capacity. Specific information that can be obtained include: melting and decomposition temperature(Taylor, 1962). DSC was conducted in Leather Industry Development Institute (LIDI) laboratory.

3.3.5.2 Thermo Gravimetric Analysis (TGA)

Thermo Gravimetric Analysis (TGA) is an instrumental techniques applied to measure the amount and rate of change in weight as a function of time and temperature in a controlled atmosphere.

The thermal stability for materials was tested by measuring the mass loss during a heating ramp rate. Thermal stability of the the materials were determined by thermogravimetric analyzer (TA instrument, SDT Q600V20.9 Build 20) using temperature programming from 25 to 800^oC at the heating rate of 20^oC/min to which the sample was heated. For the thermo gravimetric analysis to be carried out, small amount of the sample which are 17.5390 mg plastic, 43.4630mg powder from terrazzo tile and 164.4740mg river sand was placed in a vial, which was present in the TGA analyzer. This vial was connected to sensors which detects the weight of the sample at all times.

Testing was carried out under inert atmosphere (N_2) with a flow rate of 2 ml/min to remove all corrosive gases and avoid thermoxidative degradation and the retention time of the sample at the maximum temperature. These values were used as basis for the analysis. TGA was performed in Leather Industry Development Institute (LIDI) laboratory. The thermal degradation onset temperature and the thermal degradation weight loss of composites were recorded and analyzed using origin pro 8.0 software. The TGA and DSC equipment was operated simultaneously as it is found jointly.

3.4 Experimental Design

To determine experimental arrangement and to analyze the effects of process parameters on the properties of terrazzo tile, design expert 6.0.8 software was used. In order to determine where the combination of the factors give terrazzo tile with better strength, three factors: HDPE plastic waste to river sand composition, particle size of the river sand and molding pressure was considered. From Response Surface Method (RSM), Box Behnken design(BBD) for three levels of each factor was used. Based on the BBD, 17 experiments in which there are five center points were performed. ANOVA was chosen for interpretation of the results. The Box Behnken design was preferred as it gives relatively good accuracy with small numbere of experimental runs. The experiments were designed as shown in the following Table 3.

Table 3: Experimental Factors Random Arrangement in Box Behnken Design

Run Orders	**Percentage of Plastic (%)**	**Sand particle size(mm)**	**Pressing pressure(MPa)**	**Flexural Strength(MPa)**
16	35.00	0.38	6.00	
15	45.00	0.38	6.00	
3	35.00	0.85	6.00	
11	45.00	0.85	6.00	
17	35.00	0.61	2.00	
8	45.00	0.61	2.00	
1	35.00	0.61	10.00	
4	45.00	0.61	10.00	
2	40.00	0.38	2.00	
12	40.00	0.85	2.00	
10	40.00	0.38	10.00	
14	40.00	0.85	10.00	
5	40.00	0.61	6.00	
7	40.00	0.61	6.00	
13	40.00	0.61	6.00	
9	40.00	0.61	6.00	
6	40.00	0.61	6.00	

3.5 Experimental Setup and procedures for Production Terrazzo Tiles

Terrazzo tiles were produced using melting, blending, molding and discharging procedures. The detail production process included raw material collection, sorting, cleaning, melting, mixing and molding. The dried river sand was first sieved into three particle sizes(0.375, 0.605and 0.855mm). the cleaned and dried HDPE plastic waste was melted in metal drum using heating mantle at heat source. The melted HDPE plastic waste was then mixed with grinded and sieved river sands and moulded into the required terrazzo tile. The product was then cooled, labeled and trimmed. Cooling was done using ambient temperature.

The process block diagram for the main processes for production of terrazzo tiles from plastic waste and river sand blend is given as explained in Figure 6.

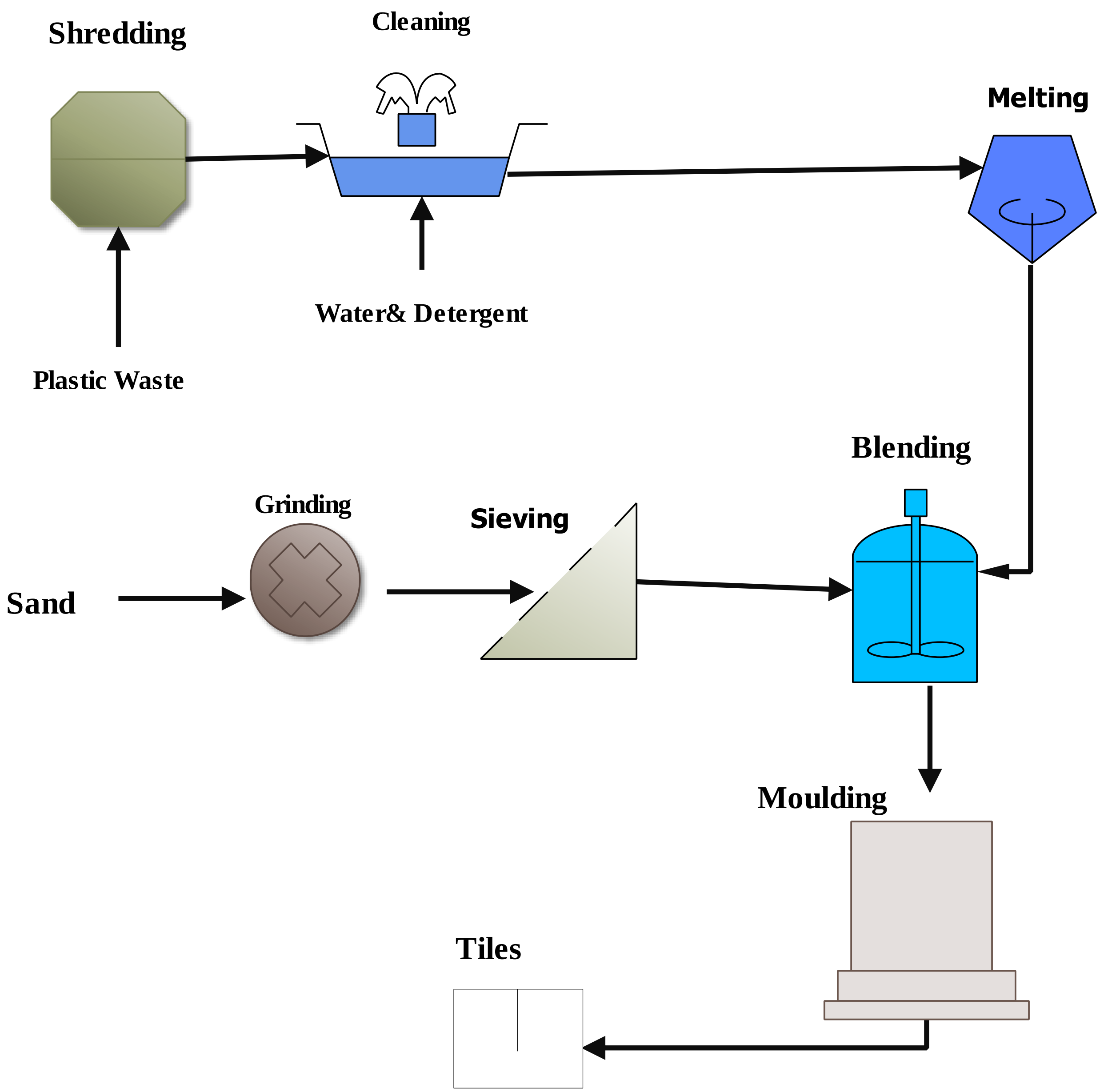


Figure 6: The main process of terrazzo tiles production

3.5.1 Raw Materials Preparation

For all 17 experiments the same amount of the summation of raw materials was taken. Taking the summation quantity of 1000g as the basis, the mass of HDPE plastic waste and river sand was calculated based on their percentage used in the production.

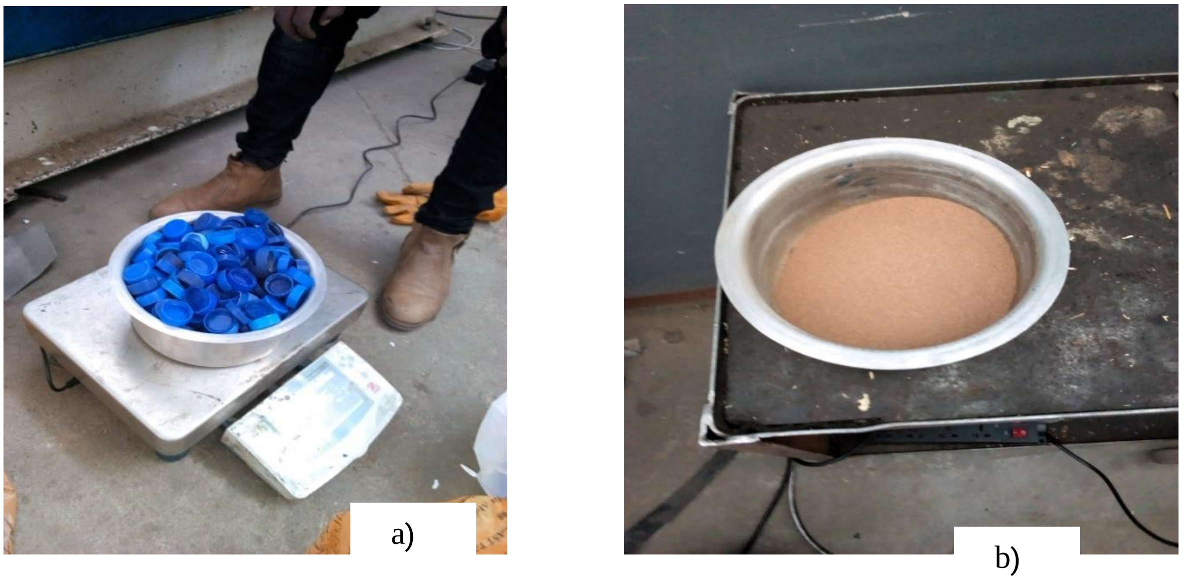


Figure 7: a) Weighing the plastic lids and b) River sand

Example

For experiment 1, percentage of the HDPE plastic waste and the river sand used were 35% and 65% respectively. The particle size of the sand was 0.38mm and the pressure load applied by hydraulic pressing machine was 6MPa. Taking the 1000g as total weight of the raw materials as basis, the mass of sand and plastic waste were calculated as follow.

Mp = 0.35x1000 = **350g**

Ms = 1000 - 350 = **650g**

Where Mp and Ms are mass of HDPE plastic waste and river sand. The calculation was done in the same way for all runs.

3.5.2 Melting and Mixing

The HDPE plastic waste, the drinking water's bottle lids, were melted in a metal drum using heating mantle as heat source. Heating was continued until the plastic was completely melted. Derric Dean suggests melting temperature of non-branched HDPE to be 160^{o}C (Dean, 2017). According to the present study, melting of the plastic to the temperatue of 160^{o}C gives a composite with better flexural strength. This study also used the temperature of 160 ^{o}C to melt the HDPE plastic waste. To measure the temperature, thermometer was employed. Results from DSC analysis for HDPE Waste characterization also proved that HDPE melts at a temperature of 160 ^{o}C. At the above temperature range the plastic waste was totally melted and liquefied in 20 minutes.

Once the plastic was liquefied, it was blended manually with river sand by using wooden stirrer. Continuous stirring is followed to make the mixture homogeneous as much as possible(Konin, 2011). However, for large scale industrial production, automatic mixer is recommended. According to Guendouz, the flexural strength increases with plastic composition but declines after 40% (Guendouz et al., 2016). Using the above as the reference, the waste plastic composition for the current study were analyzed with the HDPE plastic waste composition of 35% , 40% and 45%. The rest un mentioned composition is reserved for river sand composition. Sample preparation for melting, mixing and the mold used were shown below in Figure 5.

3.5.3 Molding

Rigid steel mold was used in the manufacture of the tiles and filled manually with the melted plastic waste and sand blend. For large scale production, pouring the blend and dischariging the tiles need to design automatic and continuous process. The blend was prepared by varying the composition ratio of HDPE plastic waste to river sand using the total quantity of 1kg as basis. The blend in the mold was then hydraulically pressed to the required pressure for 13 minutes step by step. The pressing has two successive steps. First, the blend was rapidaly transferred to the mold and pressed to 1MPa for 5 minutes. This was done to make the blend to gain the shape of the mold. Next, it was pressed by applying the required pressure for 8 minutes. Pressing pressure was increased gradually in order to ovoid out flow of the blend. Due to shapeablity of plastic materials, the pressing load has to be a pressure less than for the marble tile. For this study the pressure used were 2, 6 and 10MPa. This pressure rang was obtained by trial and error method. Colourants such as iron and silcon oxides can be added to make colored tiles.

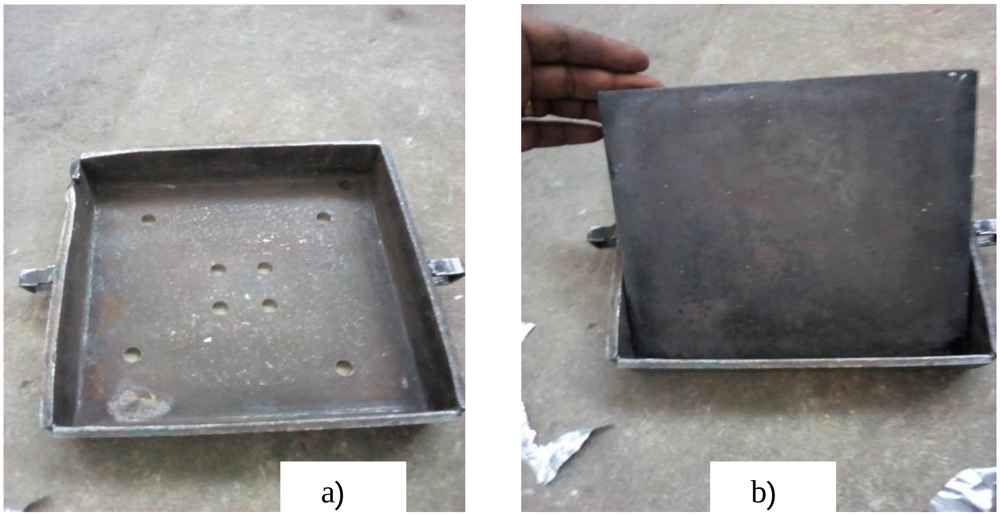


Figure 8: a) Mold with its hole, b) Mold with metal sheet for supporting terrazzo tiles

The model mold for this terrazzo tile was prepared from steel metal sheet into the size of 20cm by 20cm and thickness of 3.8cm. the metal sheet used for preparing the mold has athe wall thickness of 5mm. Metal sheet with this large thickness was preferred to avoid bending of the mold upon application of pressure load during hydraulic pressing. In addition to the mold, a smooth metal sheet which cover the internal floor of the mold was used. This is used to cover the holes on the bottom part of the mold and to support the terrazzo tile and ovoid direct impact force during the discharging process. The mold with its parts is shown in the Figure 8 (a) and (b). In order to avoid sticking of the blend to the molding wall and to simplify the discharging of the produced terrazzo tiles from the mold, the internal part of the mold was sealed with almunium foil. For large scale production, molds of stainless steel is recommended.

The produced terrazzo tile was discharged out of the mold by pushing up the metal sheet supporting the tile using the whole designed beneath the mold. Discharging was carried out before the complete cooling of the product in order to simplify the discharging process. If the produced terrazzo tiles is fully ccoled inside the mold, it is difficult to discharge it simply. It can also be broken when hammered with high impact force. After discharching from the mold, the terrazzo tiles were allowed to cool at room temperature before carrying out further analysis on them. Cooling takes 1 to 2 hours based on the weather conditions. It requires less times than other terrazzo tiles production methods such as concrete and cement terrazzo. The heated and blended mixture of plastic and sand can also be pelletized using granulator or pelletizing machine. The pellet can then be further processed to different products such as fences, beams, polls, benches etc.

Figure 9: Hydraulic Pressing Machine Setup

To discharge the produced terrazzo tile from the mold, the lid of the mold was opened using tong. The produced terrazzo tiles were discharged manually using metal rod. The rod was pushed through the hole undernearth of the mold it pushed the tile suppurting metal sheet as shown below in the Figure 10 (a) and (b).


a)


b)

Figure 10: a) Opening the mold cover, b)Discharging of the tile from the mold

3.6 Characterization of Phyisico-Mechanical Properties of Terrazzo Tiles

Properties of the product were analyzed and compared to the building code standards and to that from literature. The main tests which were conducted to test the performance of the product include: Water absorption, microstructure or surfase morphology and bending or flexural strength tests. All these tests were conducted following the conventional procedures and standards.

3.6.1 Water Absorption Test

Mechanical properties and moisture absorption behavior are related to each other. Tiles which absorb less water will show better mechanical properties. The standard methods for water absorption are mostly short-term tests; hence the results obtained are limited only to surface diffusion phenomena and not equilibrium throughout the thickness of the test specimen. Water absorption test was conducted based on plastic-sand composition, weght and thickness of the product. To evaluate effectiveness of the produced tile, water absorption test was done inorder to determine the water absorption resistance capacity of the tile. The water absorption test was conducted by immersing the product in water (using water immersion test) following standard methods (ASTM C97). The test was done at room temperature and pressure.

Percentage increase in weight was calculated using the following formula as described by Murilo(Murillo et al , 2005).

$$\textbf{Water absorption}(\mathbf{A}), \% = \frac{\boldsymbol{W_f - W_o}}{\boldsymbol{W_o}} * \mathbf{100} \quad - - - - - - - - - \; (\mathbf{3})$$

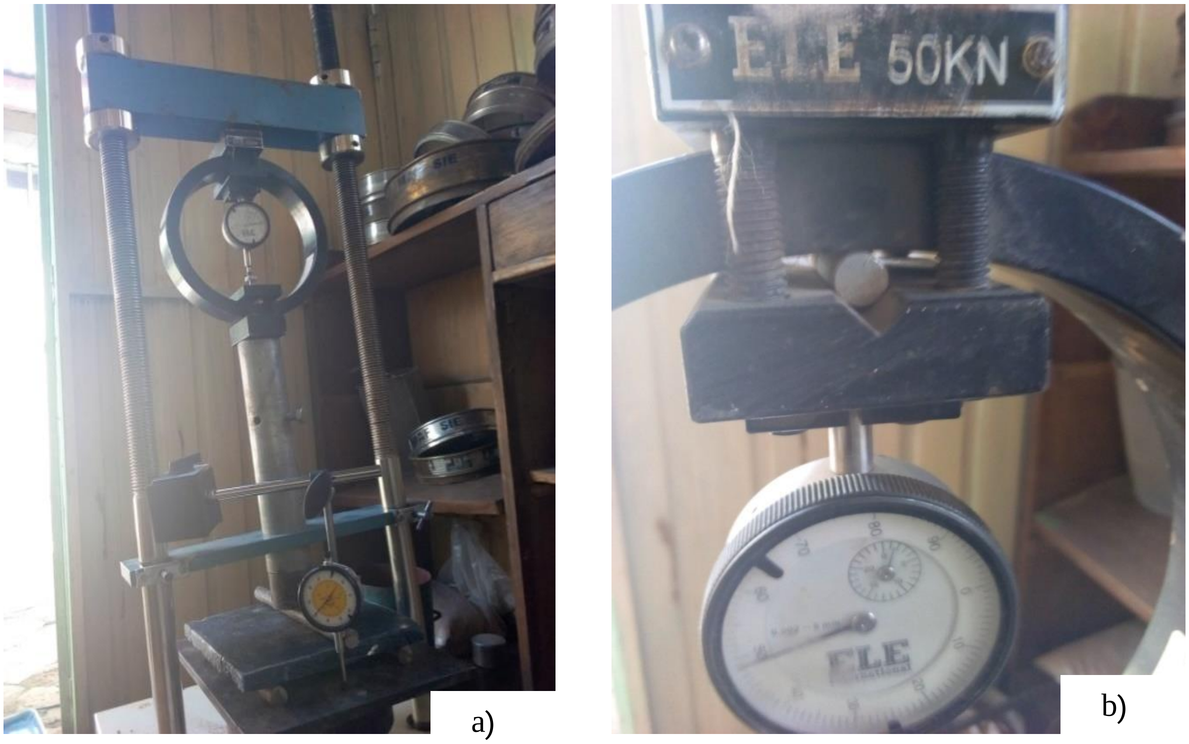
Where W_f and Wo are weight after and before immersion respectively.

3.6.2 Micro Structural (Morphology) analysis of Terrazzo Tiles

To observe how uniformily the reinforced sand was distributed in the plastic matrix, the Scanning Electron Microscopy(SEM) was employed. This helps to analyze the homogeneity and compatility of sand crystal with the plastic matrix. Scanning Electron Microscopy (SEM) has been extensively used to characterize the microstructure of terrazzo tiles. The surface morphology, such as the surface shape, pattern, and feature of the selected terrazzo tiles was observed using JEOL JSM-IT300SEM attached with Energy Dispersive X-ray (EDX). SEM was performed in Leather Industry Development Institute (LIDI) laboratory.

3.6.3 Flexural Strength Test

Flexural strength also called bending strength is defined as its ability to resist deformation under load. Flexural specimen was prepared according to ASTM D790M, three center point loading. The specimen dimension was 20 x 20 x 1.4-1.8 cm and support span was 96 mm. The force was applied by a rigid cylinder with 20 mm in diameter acting on the middle part of the metallic side of the specimen until the first crack appears in the composite. To obtain the accurate results, the surface of terrazzo tile was constantly monitored during the experiment by careful observing(Aghazadeh et al., 2011). Generally, flexural strength test is required in order to determine the amount of force that the tile can with stand on bending before breaking(Sultana et al., 2013). The reason why the flexural strength test is preferred as the main properties of the terrazzo tile is that it indirectly describes the tensile and compression strength of the material. The test was conducted at Mafcon Engineering and Construction Private Limite Company using an instrument named ELE 50 kN as shown below.



a) b)

Figure 11: Setup of flexural strength testing machine

The flexural strength(σ) was calculated using the following modified formula.

$$\sigma = 3/2\frac{fPl}{bt^2} --------------- (4)$$

Where, l = 2/3L, b = span of the specimen(mm), P =load (kN), f = 0.06166 (bending load factor), σ = flexural strength (MPa), t = thichness of the tile(mm), L = total length of the tile(mm).

The detailed calculation for it was explained in appendix C.

4. RESULTS AND DISCUSSION

4.1 Characterization of Raw Materials

4.1.1 Moisture Content

The moisture content test was conducted using oven set at 105 ^{0}C. From the literature the maximum allowable moisture content for sand was 7%, but from the experimental result the indivisual maximum and the average moisture content obtained were 0.31% and 0.18% respectively. These results show that the sun dried sand moisture content is in the requirement range and can be directly taken into the production line without the requirement of the further moisture adjustment.

4.1.2 Bulk Density of the Raw Materials

From letirature, the absolute density of the sand is 1520 to 1680 kg/cm^3 while that of HDPE is 960 kg/m^3(Olumuyiwa, 2001). While the bulk density obtained using pychnometer were 2.5064g/cm^3 for sand and 0.74 g/cm^3 for HDPE. Bulk density characterization was done to brief if the information of raw materials which related to material packaging and material handling are requied.

4.1.3 XRD Analysis of the River Sand Particles

Figure 12 shows XRD results of river sand. The gragh for the XRD shows sharp peaks, which indicates a crystalline nature of the material under the investigation(Sultana et al., 2013). In the figure, the intensity are high around the angle 2θ of 20.99°, 24.34°, 26.98°, 36.92°, 50.59°, 60.19° and 68.12°. The XRD spectra shows that sand exhibits sharp peaks which reveal its crystalline nature. The crytallity property is one of the indication that shows the material used is a sand similar to that is used in construction sector.

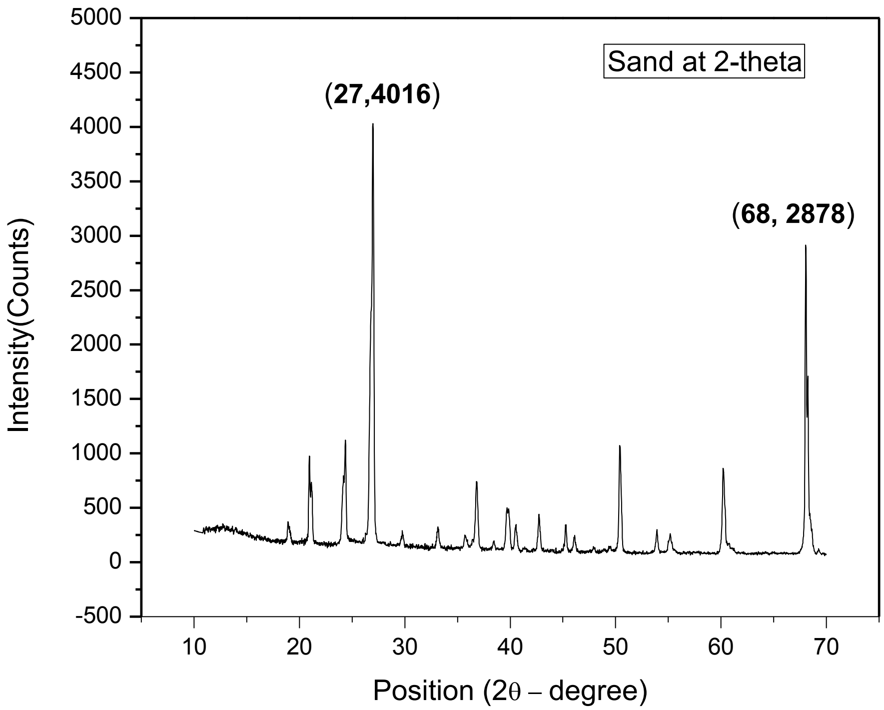


Figure 12:XRD Result of Sand particles

4.1.4 FTIR Analysis of River Sand, HDPE Plastic waste and Terrazzo Tiles

Figure 13 is the FTIR graphs of river sand, HDPE plastic waste and terrazzo tile. From the figure, in the range of the wave number 4000-3800 cm^{-1}, the FTIR patterns of the tile, the HDPE plastic waste and the river sand are almost similar, they differ in the intensity of the peak. For all of them, the strong peak at 3438 cm^{-1} shows stretching of H-bonded of O-H functional group which can be phenol. This agrees with the works of Rajia Sultana and his coworkers(Sultana et al., 2013). Between the wave number 2800 and 2500 cm^{-1} the tiles follow the patterns of HDPE than that of the sand.

From the blue graph for the terrazzo tile, a strong band at 1080cm^{-1} is observed due to the presence of silica, which may come from the used river sand. A strong band at 1080cm^{-1} reveals the formation of Si-CH_2 bond. This shows the interaction of the HDPE with the silica in the river sand. Peaks in lower energy areas on an FTIR graph are collectively known as the fingerprint region. Each region is unique for an individual compound and are thus extremely helpful in comparisons between different FTIR graphs(Petrovich, 2015). After the wave number of 700 cm^{-1}, the pattern which the produced terrazzo tiles follow pretends that of the sand. Eventhough the sand and HPDE are changed due to the process factors, the tile has taken properties of the both. As there is no much significant disappearance of the peaks and changes in the pattern, the processing factors influences physical properties than chemical properties of the raw materials used for the production of terrazzo tile. The correlation table for the FTIR analysis is given under appendix E.

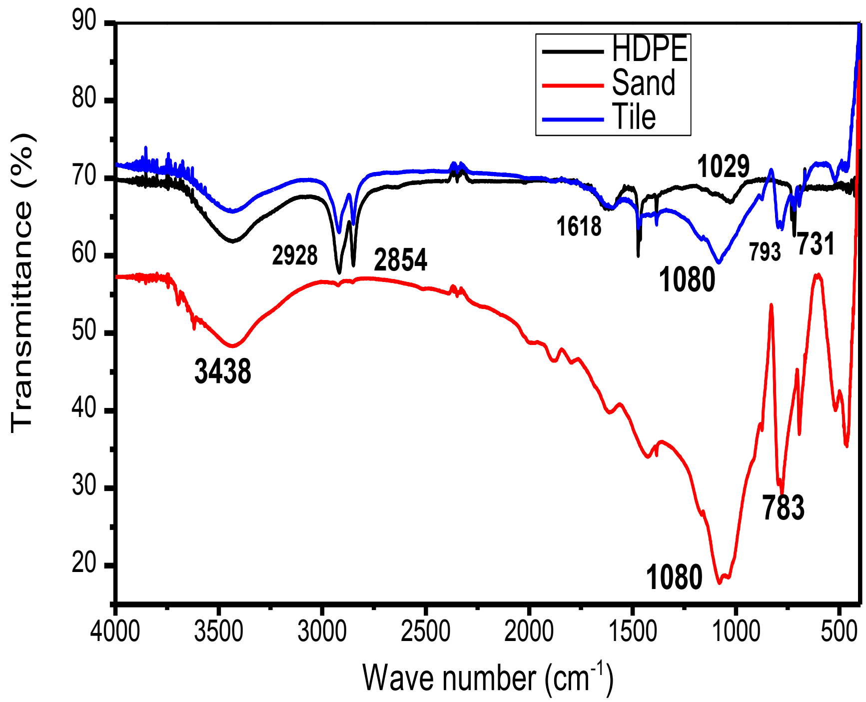


Figure 13: FTIR Analysis Result

4.2 Thermal Properties of the Terrazzo Tiles

4.2.1 Differential Scanning Chalorimetry Analysis

In Figure 14, the green graph depicts DSC trend of terrazzo tile while the blue graph shows the TGA trend of it. From the DSC gragh in the figure, there are two main endothermic(Kodre et. al, 2014) peaks. They are at 160^0C and 470^0C. The huge energy consumed at 160^0C without significant change in weight is absorbed due to the phase change during the melting of HDPE. This one of the indication that proves as the plastic waste used was HDPE. The energy consumed at the second peaks(470^{0}C) is due to decomposition of HDPE into CO2 and gases. The degradation attributes to thermal cracking of the hydrocarbon chains and the production of oxyginated hydrocarbons CO, CO_2 and H_2O that confirms with that of Fare et al.(Banat & Fares, 2015).

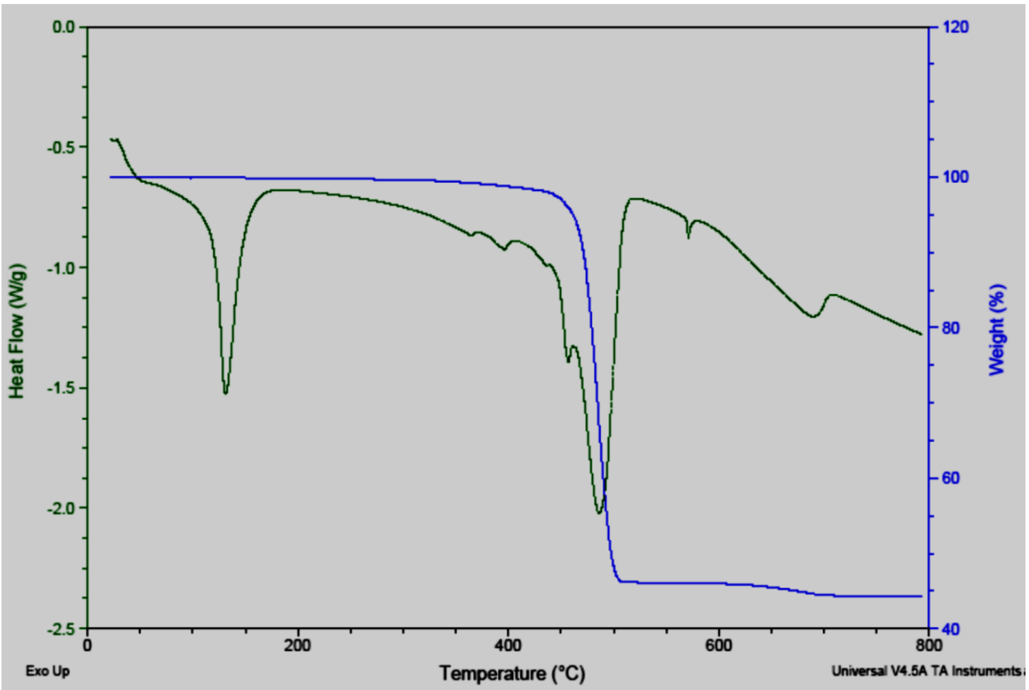


Figure 14: DSC-TGA for terrazzo tiles

4.2.2 Thermogravimetric Analaysis

Figure 14 shows the TGA and DSC terrazzo tiles. In the HDPE and the tile samples, the rapid weight loss is observed between the temperature of 450-500 ^{0}C. After the temperature of 500^{0}C, there is only 55% of the terrazzo tile's material remained. So the terrazzo tile has ablity to with stand only temperature upto 450^{0}C without beng decomposed. But after the temperature of 450^{0}C, about 51% weight is lost. This is due to the decomposition of the HDPE plastic. As understood from Figure 20 and Figure 21 under the appendix G, the thermal property of the tile follows property of the plastic than that of the sand. This may due to that, as the binding plastic is burnt out, the bonding forces of the tile is loosened and it will decomposed. The other reason can be sampling error which may occur during sample's specimen preparation from terrazzo tiles for TGA and DSC analysis. In any ways, the results from DSC and TGA show that the terrazzo tiles has to be used in the application area whose temperature does not exceed 450^0C.

4.3 Phyisico-Mechanical Characterization of Terrazzo Tiles

4.3.1 Water Absorption

The water absorption test was conducted for all 17 expermental samples in a randomized order and the result was tabulated as follow in Table 4.

Table 4: Water absorption percentage of Terrazzo Tiles

Experimental Run order	**Samples theckness(mm)**	**Water Absorption Percentage (%))**
16	16	0.032
15	15	0.09
3	18	0.027
11	15	0.282
17	17	0.008
8	17	0.203
1	17	0.041
4	14	0.013
2	16	0.021
12	17	0.031
10	16	0.216
14	17	0.0329
5	17	0.213
7	16	0.268
13	16	0.096
9	17	0.276
6	18	0.039

The average water absorption percentage obtained is 0.11% while the maximum individual sample water obsorbe was 0.28%. The water absorption capacity of the trrazzo tiles may be reduced due to less micro-pores exist in the produt as observed SEM in figure 19. Another reason may be from the plastic properties of water hating(hydrophobic). From the result of water absorption test, we conclude that the ability of the tile to resist water obsorption is in agreement with British standards which is 0.5% maximum for terrazzo tiles(Delhi, 1998).

4.3.2 Flexural Strength

The reason why the flexural strength test is preferred as the main properties of the terrazzo tile is that, it indirectly describes the tensile and compression strength of the material. From the test, as pressure increases the strength decreases. It is also difficult to press the molten plastic and sand mixture with higher pressure, because as pressure rises the mixture flows out of the mold in its molten state. The minimum and the maximum flexural strength obtained were 12.44 MPa and 20.7 MPa respectively and agree with(Mengeloglu & Karakus, 2008). While the average is 17.49 MPa. This confirms with J. Aghazadeh Mohandesi and his coworker's study results(Aghazadeh et al., 2011). According to British standard(BS 4131) the minimum flexural strength required for terrazzo tile is 3MPa. This shows that the produced terrazzo tiles can with stand loads before breaking. The detailed information can be abtained from Table 5.

Table 5: Flexural Strength of Terrazzo Tiles

Run	Percentage of Plastic (%)	Sand particle size(mm)	Pressing pressure(MPa)	Flexural Strength(MPa)
16	35.00	0.38	6.00	18.71
15	45.00	0.38	6.00	16.11
3	35.00	0.85	6.00	19.30
11	45.00	0.85	6.00	17.50
17	35.00	0.61	2.00	17.01
8	45.00	0.61	2.00	13.26
1	35.00	0.61	10.00	14.90
4	45.00	0.61	10.00	12.44
2	40.00	0.38	2.00	14.80
12	40.00	0.85	2.00	19.40
10	40.00	0.38	10.00	14.27
14	40.00	0.85	10.00	15.10
5	40.00	0.61	6.00	19.90
7	40.00	0.61	6.00	18.90
13	40.00	0.61	6.00	19.60
9	40.00	0.61	6.00	18.4
6	40.00	0.61	6.00	20.7

4.4 Effects of Process Parameters on the Flexural Strength

Process parameters considered under this study are HDPE plastic waste to river sand composition, the river sand particle size and pressing pressure used for molding purpose.

4.4.1 Analysis of Variance

ANOVA is used to identify the significance of the process variables considered and their interaction effects. The ANOVA result which shows theeffect of the process parameters on the flexural strength of terrazzo tile is displayed by the next Table 6.

Table 6:Analysis of variance (ANOVA) for flexural strength of terrazzo tile.

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	Remarks
Model	104.88	9	11.65	16.82	0.0006	Significant
A (Plastic composition, %)	11.54	1	11.54	16.66	0.0047	>>
B (particle size of Sand, mm)	6.86	1	6.86	9.9	0.0162	
C(pressing pressure, MPa)	9.599	1	9.59	13.84	0.0075	
A^2	11.71	1	11.71	16.89	0.0045	
B^2	0.022	1	0.022	0.032	0.8632	
C^2	57.02	1	57.02	82.18	<0.0001	
AB	0.16	1	0.16	0.23	0.6455	
AC	1.31	1	1.31	1.89	0.2114	
BC	0.3.55	1	3.55	5.13	0.0580	
Residual	4.85	7	0.69			
Lack of Fit	1.67	3	0.56	0.7	0.5990	Not Significant

The Model F-value of 16.82 implies the model is significant. There is only a 0.06% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B,C, A^2, C^2 are significant model terms. This shows that all the considered process variables (percentage of the plastic waste; particle size of the river sand and the pressing pressure) significantly affect the flexural strength of the terrazzo tiles. As descried by design expert, the Values greater than 0.1000 indicate the model terms are not significant. According to this AB, AC, BC and B^2 are not significant. This means that, the interaction between plastic persentage and the sand partcle size, plastic persentage and pressing pressure, sand particle size and pressing pressure do not affect flexural strength of the tile significantly.

The "Lack of Fit F-value" of 0.7 implies the Lack of Fit is not significant relative to the pure error. There is a 59.90% chance that a "Lack of Fit F-value" this large could occur due to noise. Not significant lack of fit is good because we want the model to fit. From the above results, the developed second order quadratic model provides an adequate approximation of the actual values on the response flexural strength of terrazzo tiles.

4.4.2 The Main Single Effect of Process Variables

From analysis of variance(ANOVA) displayed by Table 6, it is observed that the percentage of HDPE plastic waste, the particle size of river sand and pressing pressure have significant effects on the flexural strength of the terrazzo tiles. From the single effects plotted in Figure 15 a), one can obseve that the flexural strength of terrazzo tiles increases slowly from 19.03MPa to 19.6MPA as the plastic percentage increases from 35 to 40%. The the flexural strength then started to decrease fastly from 19MPa to 17MPa as the plastic percentage increases from 40% to 45%. This indicates that the better flexural strength is obtained at the optimum plastic percentage of 40%. Figure 15 b) shows that as sand particle size increases from 0.38mm to 0.85mm, the flexural strength of terrazzo tiles increses linearly from 18.6MPa to 20.5MPa. This indicates that the sand particle size and flexural strength of terrazzo tiles have direct relationship in the considered sand particle size.

Lastly, Figure 15 c) conveys that flexural strength of the terrazzo tiles increases exponentially from 16.92 MPa to 19.6 MPa as the pressing pressure increases from 2MPa to 6MPa. It then rapidly decreases to 14.73 MPa as the pressing pressure decreases to 10 MPa. This indicates that the optimum pressure required to produce the terrazzo tile with better flexural strength is 6 MPa.

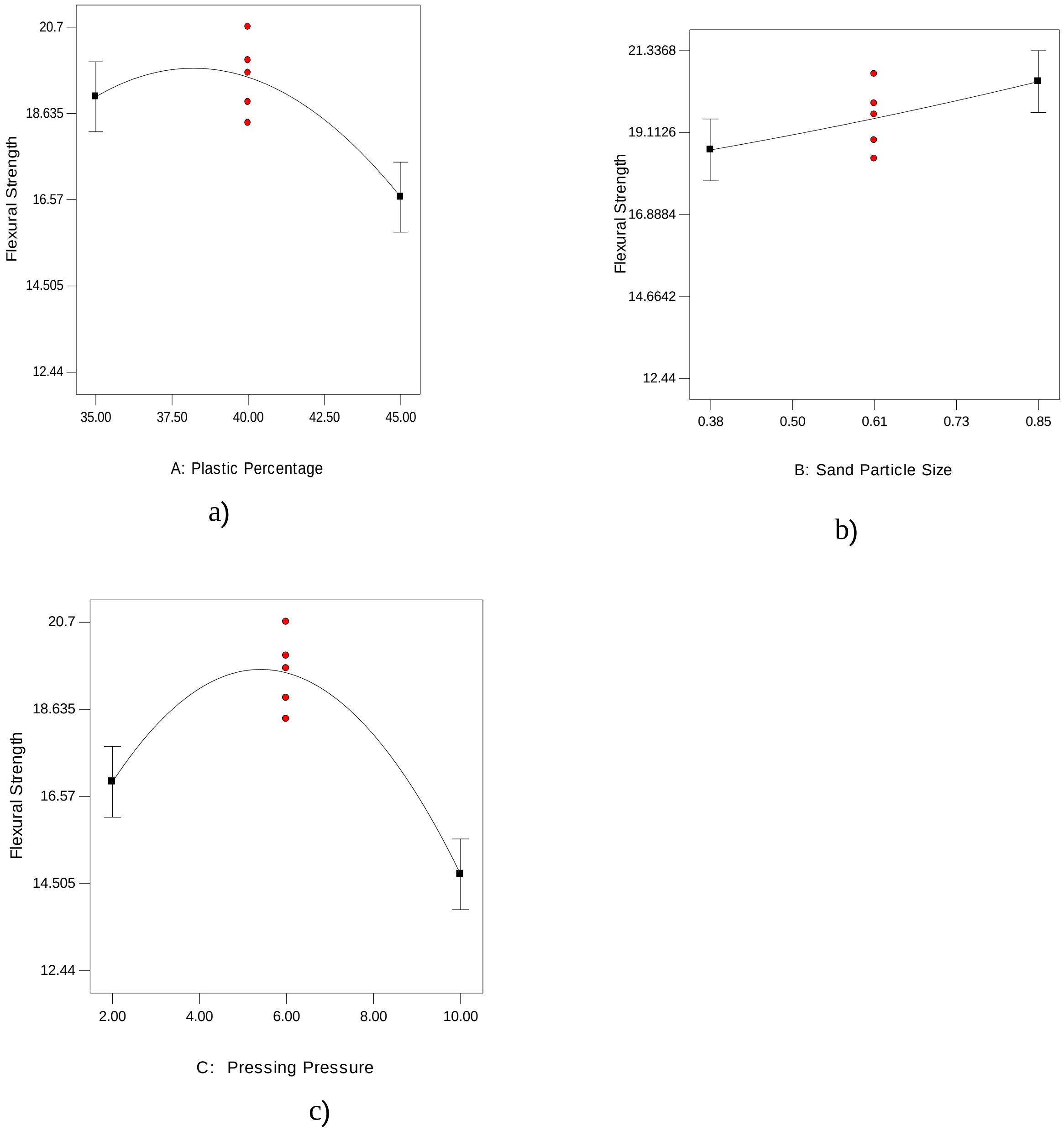


Figure 15: Single Effects of Process Variables on the Flexural Strength of Terrazzo Tiles

4.4.3 The Interaction Effects of Process Variables

Eventhough ANOVA shows that there are no significant interaction effects of process parameters on the flexural strength of the terrazzo tiles, the 2D plots in Figure 16 and the 3D plots in Figure 17 illustrates the existence of the interaction effects of the process variables.

From Figure 16 b) and Figure 17 b) the plastic percentage and pressing pressure have few synergetic effects on the flexural strength of the terrazzo tiles upto the plastic percentage of 38% and pressing pressure of 6MPa. Increasing their values from there, result in the decreament of the flexural strength.

As observed from Figure 16 a) and Figure 17 a), increasing the sand particle size at lower percentage of plastic binder gives better flexural strength in the considered range of these two experimental variables.

As displayed by Figure 16 c) and Figure 17 c), flexural strength of the terrazzo tiles increses linearly as sand particle size increases from 0.38 mm to 0.85 mm at the constant pressing pressure of 6 MPa.

From the results discussed above, it can be concluded that all the considere process variables have both the single effect and the interaction effects on the flexural strength of the terrazzo tiles.

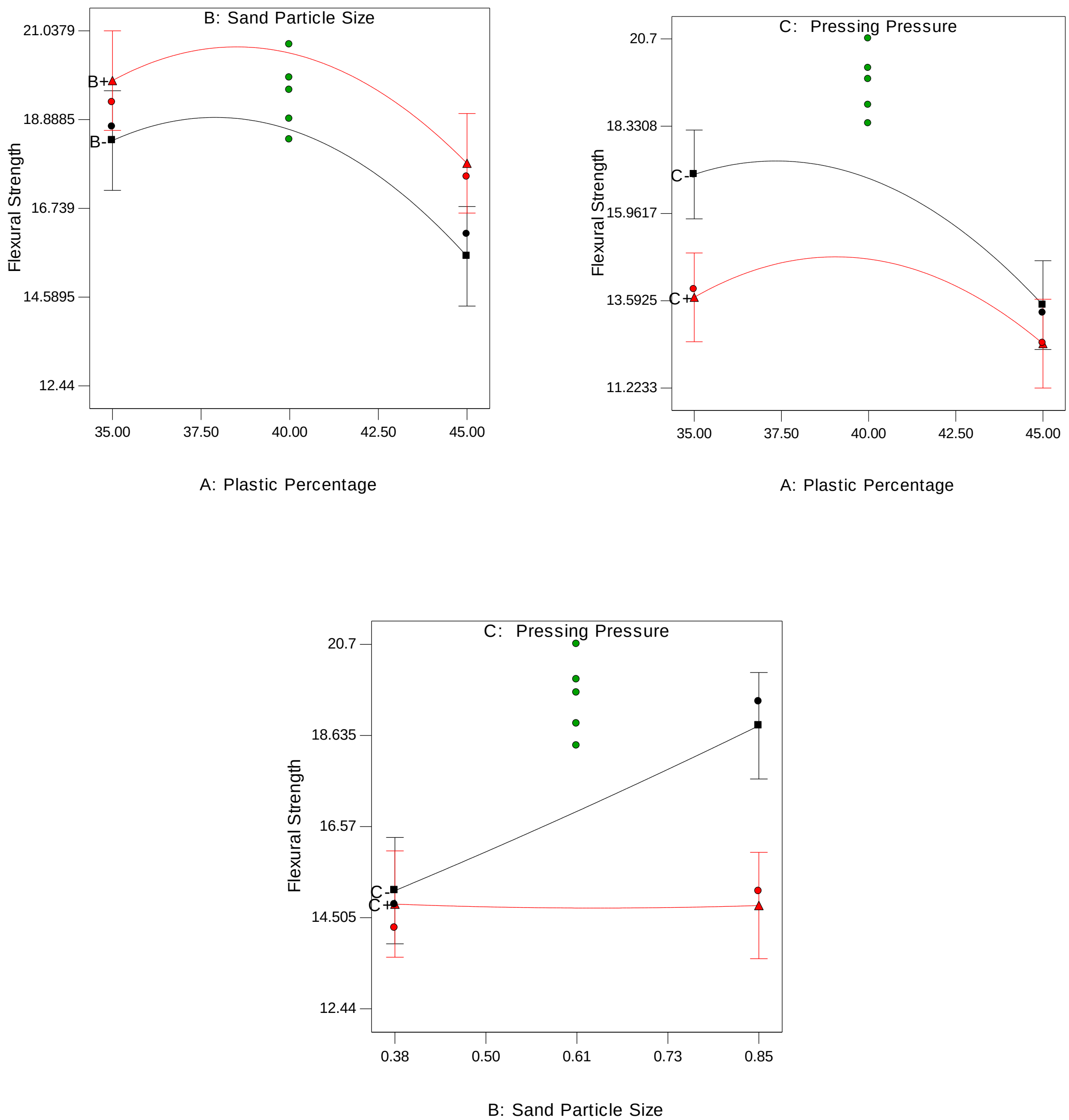


Figure 16: Interaction Effects of Process Variables on the Flexural Strength of Terrazzo Tiles

The 3D plots reveal the interaction effects of the process variable better and the the plots are depicted below.

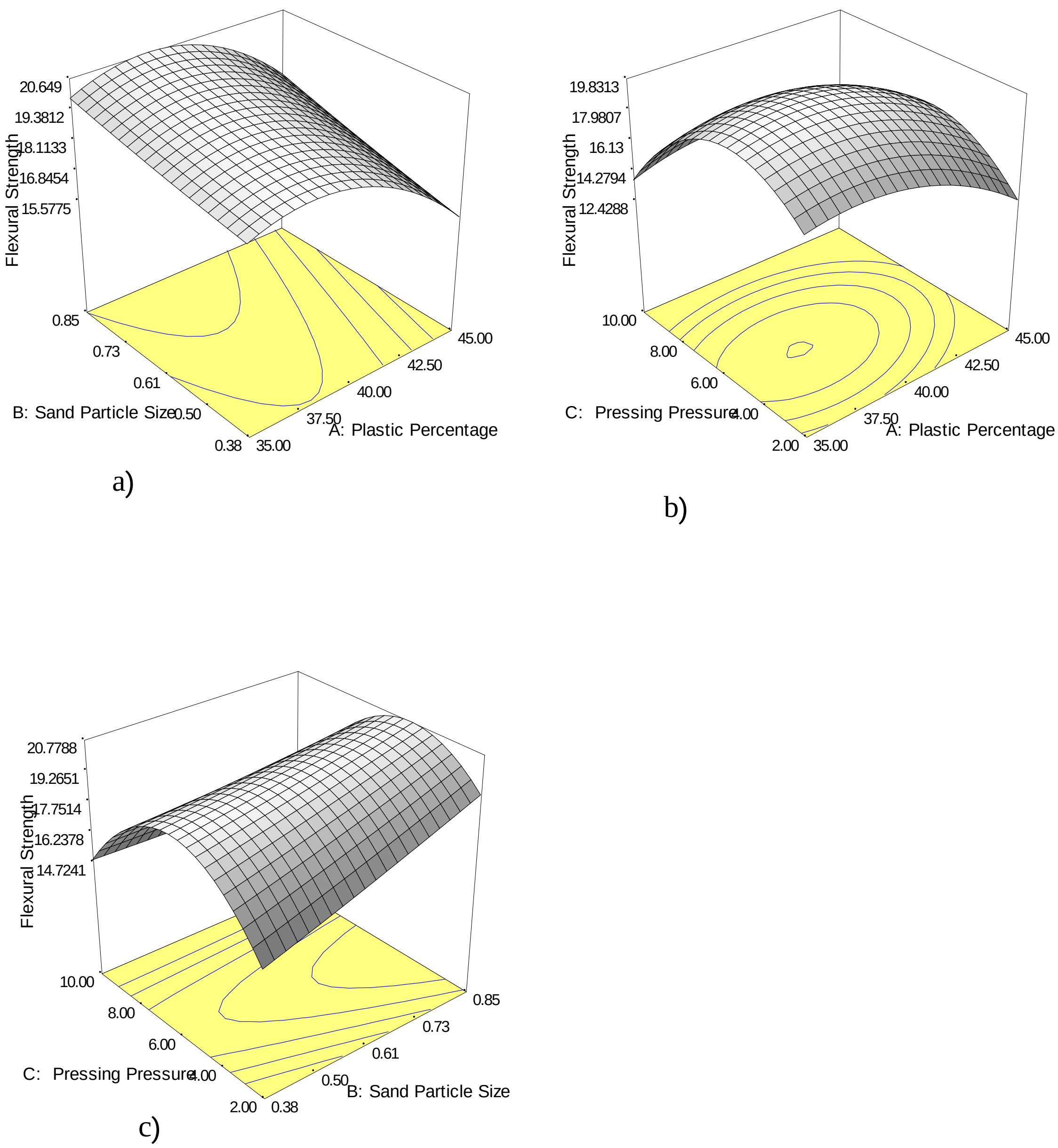


Figure 17: 3D Visualization of Interaction Effects of Process Variables on the Flexural Strength of Terrazzo Tiles

4.5 Development of Model Equation

Model equation that relates the response (flexural strength) to the production process parameters interms of actual values after excluding insignificant terms was developed using analysis of variance and given given below by equation (5). To determine the model equation, analysis from the sequential model sum of squares, lack of fit tests and model summary statistics were found that quadratic model equation is the most suitable model for the present study. This is because the quadratic model has higher R-squared, adjusted R-squared and pridcted R-squared for the flexural strength of the terrazzo tiles.

$$Flexural\ Strength = -86.33769 + 5.08354 * Plastic\ Percentage + 3.85937 * Sand\ Particle\ Size + 2.48339 * Pressing\ Pressure - 0.066547 * Plastic\ Percentage2 - 0.22976 * Pressing\ Pressure2 - - - (5)$$

In the model equation, the coefficients of the factors show the effect of that factor. The positive sign denotes the synergetic effect while the negative sign denotes an antagonistic effect.

4.6 Checking Model Adequacy

Adequacy of the model was checked using ANOVA, R-squared and residual plots as explained below.

4.6.1 Analysis of Variance (ANOVA)

The adequacy of the developed model can be checked by using diagnostic plots (normal probability plot, residual plots, outlier), ANOVA statistics, lack of fit.

Table 7: The various R-squared

Std. Dev.	0.83	R-Squared	0.9558
Mean	17.02	Adj R-Squared	0.8990
C.V.	4.89	Pred R-Squared	0.7111
PRESS	31.71	Adeq Precision	11.596

From the lack of fit test shown, it is clear that the second order quadratic model suggested by the design expert was suitable because the lack of fit was insignificant (prob>F is 0.5990). The insignificant lack of fit is desirable for the model to fit the experimental data properly. As shown in Table 7, the coefficient of determination (R^2) for regression model is 95.58% which implies that the model accounted 95.58% variability in the data.

4.6.2 Residual Plots for Flexural Strength

As shown in the above graphs, normal plot of residues, residual vs predicted, residual vs run and outlier tells the validity of the model with the fitted data. The normal probability plot shows each data is fitted to the straight line; implies that the response flexural strength abtained from the experimental data is agreed with the assumption of the regression model. It means that the error is normally distributed with the maean of zero. That is why the data are normally distributed and make straight along a line. The residual vs predicted plot shows that no regular shape is observed between the experimental data and the predicted values which shows that the data taken were collected randomly in the experiment.

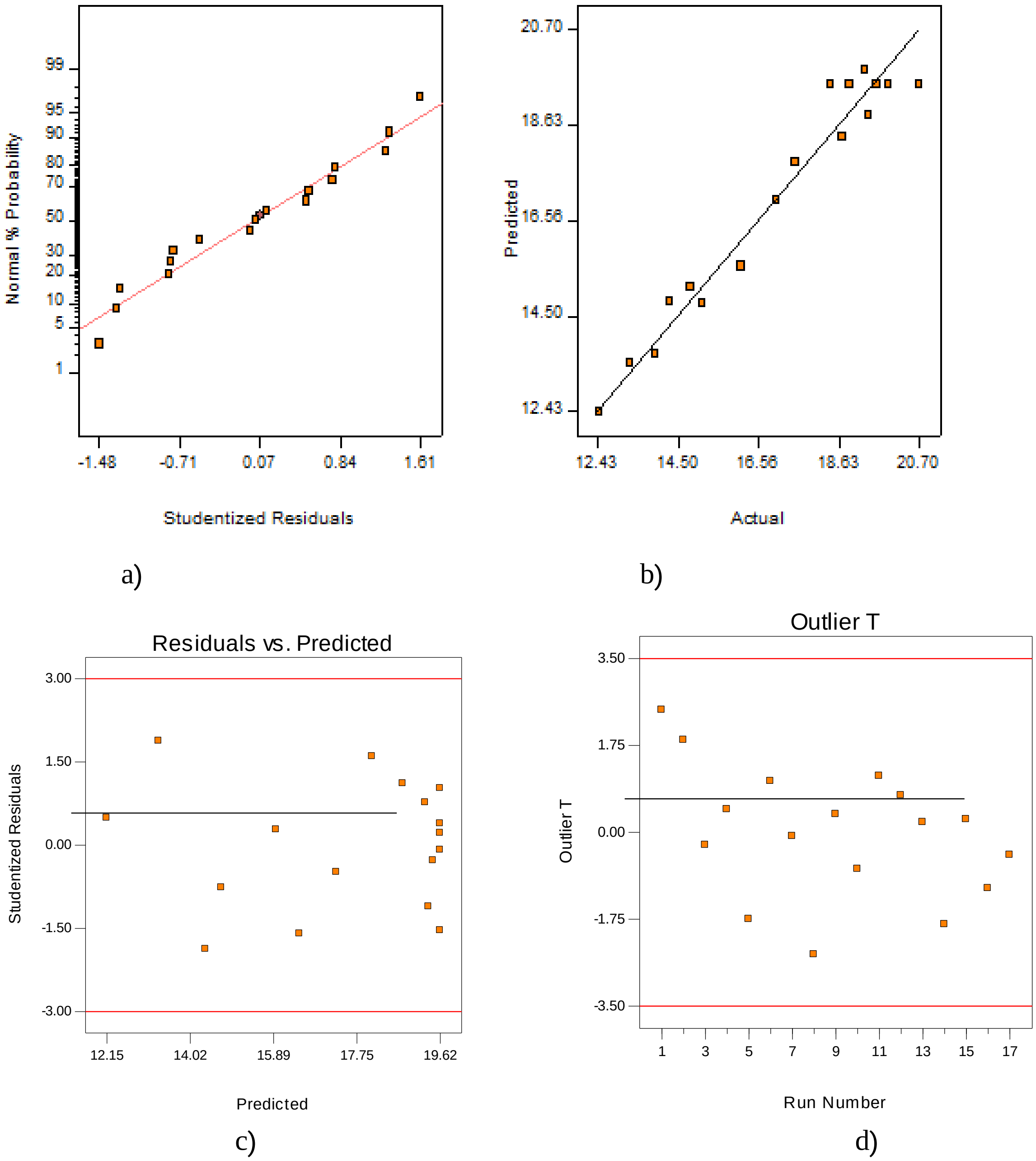


Figure 18: The diagnostic and residual plots

Outliers T vs run numbers graph tells if there is bad data in the experiment, whether the experiment has been done in the appropriate condition or not. As seen from the graph in the Figure 18 d), there is no point gone out of the limit boundry. This shows that there is no bad data which needs to be repeated.

To summarize, all the considered model edequacy checking methods showed that the developed quadratic model best adequately fits the response, the flexural strength of the produced terrazzo tiles.

4.5 Micro Structural (Morphology) Analysis

For the surface morphology analysis of the produced terrazzo tiles, the tiles with maximum flexural strength was preferred and seen under SEM at different magnification. The test was conducted to check how much uniformily the sand particle was distributed in the HDPE matrix of the produced terrazzo tile by taking the tile with the optimum production factors conditions(40% sand, 0.61 particle size and 6MPa pressing pressure). The results are shown by Figure 19. The white spots shown by the arrows represents the sand particles while the left blackish area represents the plastic matrix by which the sand particles are bonded together. The SEM image shows that the silica particles are dispersed well with certain degree of homogeneity even when seen at different magnification. There is no much significant micropores and craks are visible compered to the conventional concret terrazzo tiles. This may be why the water absorption of the terrazzo tiles is 0.18% wich is very low.

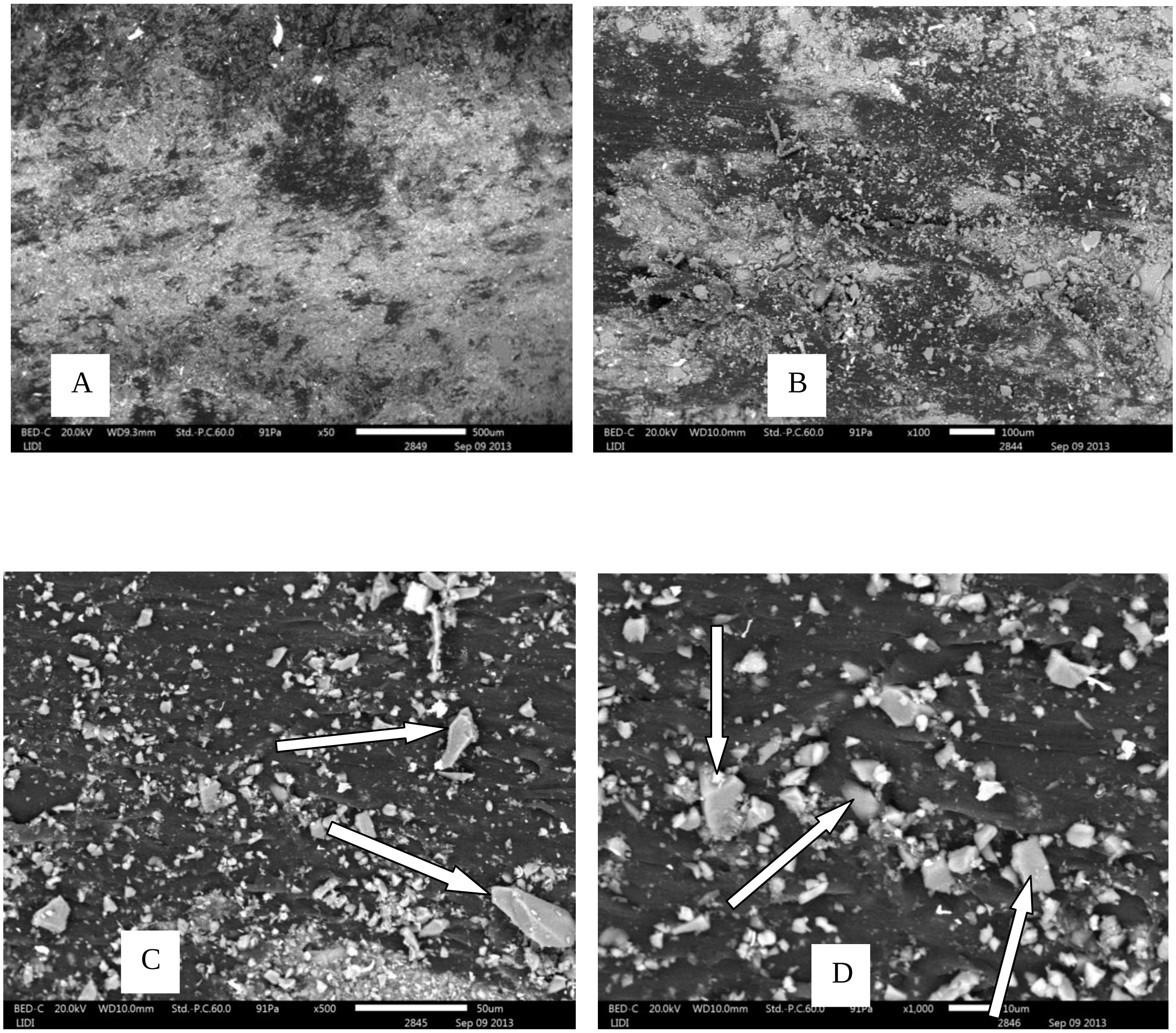


Figure 19: Surface morphology of terrazzo tiles

at A) 500µm, B) 100µm, C) 50µm, D) 10µm resolation under SEM

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The main raw materials used for the production of terrazzo tile were river sand and HDPE plastic wastes. The river sand was collected from low land area of Dhare River in bale zone of Oromia Regional State. Plastic wastes with basis of HDPE were preferred for this thesis work. This was because that different types of plastics melt and burn at different temperatures and have different physical and chemical properties. Hence, narrowing the platic waste type to only HDPE minimized the complex effects due to variation in the plastic types. The river sand in the tile acts as fire retardant and hardening agent while the HDPE plastic waste serves as bonding agent to hold the sand particles together. The presence of the plastic also reduces the breakablity of the tile when it is exposed to the bending and the impact forces. Relative to the convectional methods that uses cement, utilization of HDPE waste also helps to produce terrazzo tiles with less thickness to weight ratio so that reduces the quantity of the raw materials required. This makes it more economical in the raw materials consumption.

For the production of terrazzo tiles the main process variables considered were pressing pressure (2, 6 and 10 MPa), particle size of the river sand (0.38, 0.61 and 0.855mm), HDPE plastic waste to river sand composition (35/65, 40/60 and 45/55 %). For the produced terrazzo tiles, the maximum flextural strength of 20.7MPa was obtained at plastic to sand compostion of 40/60 %, sand particle size of 0.61mm and pressing pressure of 6MPa. The minimum flextural strength of 12.44MPa was obtained at plastic to sand compostion of 45/55 %, sand particle size of 0.61mm and pressing pressure of 10MPa. Both the obtained minimum and maximum flexural strenghths are higher than the minimum flexural strength (3MPa) set by British standard agency for terrazzo tiles to be used for out door or external application. Therefore terazzo tiles produced from river sand and HDPE plastic waste as binding agent have better flexural strength which fulfill the expected standard.

As observed from BBD, pressure is the most influencing factor within the considered process variables range. As the pressing pressure increases from 2MPa to 6 MPa, the flexural strength is increased from 19.74 to 20.7 MPa but as the pressure increses further from 6MPa to 10MPa, the flexural strength decreased to 15.53MPa. Therefore, the optimum pressing pressure determined by this thesis work is 6MPa. Other factors such as sand particle size and plastic to sand ratio do not much significantly affect the flexural strength of terrazzo tile in the considered ranges. This implies that we can use sand of partilcle size even greater than 0.855mm without the requirement of further size reduction. This makes the production more economical.

The result obtained from TGA and DSC analysis showed that the terrazzo tiles produced from HDPE plastic waste and river sand can with stand higher temperature upto 450^0C without being decomposed.

The results abtained from the tests such as SEM and FTIR showed that as there is interaction of river sand and HDPE plastic waste in the terrazzo tiles matrix so that contribute for the properties of the product. The terrazzo tiles produced in this thesis have less thickness, light weight but better flexural strength and water resistant capacity relative to the other conventional terrazzo tiles.

So, it can be concluded that utilization of HDPE plastic wastes as binding agent with river sand in the production of terrazzo tiles is possible. It gives valuable product with compareable physical and mechanical properties to the convectional terrazzo tiles. Utilization of HDPE plastic wastes as binder agent can be used as alternative to cement in production of terrazzo tiles and it can be potential input for construction sector and other engineering applications.

What makes terrazzo tiles from plastic waste special is that, it is less breakable, requires few time for aging(2-3 days) after production, it has higher flexural strength and expected to have better impact and water resistance. Generally, with its minimum thickness to weght ratio, it gives comparable physical and mechanical properties to conventional terrazzo tiles.

5.2 Recommendations

Due to the lack of temperature controlling tools for this research, the effect of temperature and cooling rate did not studied. However, it may affect the physio-mechanical and chemical properties of the product. Hence, the author recommends the future researchers to consider them.

To minimize effects due to molecular weight and melting temperature of the plastic wastes, the wastes from the same origins were used as much as possible. Before melting, plastic wastes have to be shredded into small flakes. But the availability of plastic shredder is less in Ethiopia. For this reason, the author used water battles' lids' of HDPE origin. This is because the lids size is small and easy for melting without the shredder for the size reduction. However, with the availability of shredder and molecular weight analyzer the future researcher can include HDPE plastic wastes from different packaging materials and apply it for large scale production.

Sealing the internal part of the mold with almunium foil during the production was used to simplify the discharging of the produced terrazzo tile. For large scale production, stainless steel mold is recommended.

The heated and blended mixture of plastic and sand can also be pelletized using granulator or pelletizing machine. The pellet can then be further processed to different products. The author recommends further researcher or the plastic and the tile industries to incorporate hot pressing machine and model mold and also pellitizing plastic waste to different profiles.

In order to minimize the slippery properties of the plastic, different patterns can be embossed on the surface of the terrazzo tiles. The outer surfaces can also be treated with additional sand by using heat and pressure.

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APPENDICES

Appendix A: Sieve Analysis and Sand Particle Size Calculaton

The sand was taken from the source and separated into three catagories usingsieve analysis. Thesieves were arranged in descending order on sieve vibrator. The sieves used were that of size 1mm, 710 µm, 500 µm and 250 µm. the sand size was taken as the average size of the two successive sieves and calculated as follow.

1) S1= $\frac{(1+0.71)mm}{2}$ = 0.855mm
2) S2= $\frac{(0.71+0.5)mm}{2}$ = 0.605 $\approx$0.61mm
3) S3 = $\frac{(0.5+0.25)mm}{2}$ = 0.375$\approx$ 0.38mm

The sand particle size used were 0.855mm, 0.61mm and 0.38mm. The size 0.855mm represents the particles passed the sieve with the size of 1mm but reatained on the sieve the size of 710µm.

Appendix B: Calculation Bulk Density of River Sand

Density of the sand and the HDPE were determined by displacement method using pychnometer and distilled water(at 20^{o}C and 1atm). First, weight of empty pychnometer with its cover was measured(m1). Then, half of the pychnometer was filled with the sample and its weight was taken(m2). Next, the rest of the pychnometer space was filled with distilled water and its weight was taken again(m3). Here, density of the distilled water is taken to be 1 g/cm^3. Density of the sample was then calculated as follow.

$$\textbf{Bulk density of sample} = \frac{\boldsymbol{mass\ of\ sample}}{\textbf{volume of sample}} \quad ------- \quad (3)$$

Appendix C: Calculation of Flexural Strength of Terrazzo Tile

Flexural strength test is required in order to determine the amount of force the tile can with stand on bending before breaking. The test was conducted at Mafcon Engineering and Construction Private Limite Company using an instrument named ELE 50 kN.

The flexural strength() was calculated using the following modified formula:

$$\sigma = \frac{3}{2\frac{fPl}{bt^2}} - - - - - - - - - - - - - - - (5)$$

Where, l = 2/3L, b = span of the specimen(mm), P =load (kN), f = 0.06166 (bending load factor), σ = flexural strength (MPa), t = thichness of the tile(mm), L = total length of the tile(mm).b = span of the specimen(mm)

Example: For terrozzo tiles with the run No 12, the load obtained is 161kN and the thickness is 18mm. Taking the span and length of the specimen to be 20mm, we can calculate bending/flexural strength as follow.

Given: p = 16lkN, span = L = 20mm, t = 18mm , f= 0.04166

Required: $\boldsymbol{\delta}$ = ?

Solution:

$$\boldsymbol{\delta} = \frac{0.04166 * 161 * 10^3 N * 20mm}{20mm * 18mm^2}$$

$$= \mathbf{20.7\ MPa}$$

Appendix D: Calculation of Moisture Content of River Sand

Moisture content of the river sand was calculated using the following equation.

$$Moisture, \% = \frac{W_1 - W_2}{W_1} * 100$$

Example: If the weight of the sand before drying and after drying were 1.005g and 1.4957g respectively, the moisture content percentage in wet basis will be;

$$\text{MC1}, (\%) = \frac{1.5004 - 1.4957}{1.5004} * 100$$

$$= \mathbf{0.31}\%$$

Isimilarly, moisture content of three other samples were calculated and obtained to be 0.05%, 0.19% and 0.15%. the average moisture content is then,

$$\text{MC, avg} = \frac{0.31 + 0.05 + 0.19 + 0.15}{4} * 100 = \mathbf{18}\%$$

Appendix E:Infrared spectroscopy correlation table

Bond	Type of bond	Specific type of bond	Absorption peak (cm^{-1})	Appearance
C–H	alkyl	methyl	1260	strong
			1380	weak
			2870	medium to strong
			2960	medium to strong
		methylene	1470	strong
			2850	medium to strong
			2925	medium to strong
		methine	2890	weak
	vinyl	$C{=}CH_2$	900	strong
			2975	medium
			3080	medium
		$C{=}CH$	3020	medium
		monosubstituted alkenes	900	strong
			990	strong
		cis-disubstituted alkenes	670–700	strong
		trans-disubstituted alkenes	965	strong
		trisubstituted alkenes	800–840	strong to medium

Bond	Type of bond	Specific type of bond	Absorption peak (cm^{-1})	Appearance
	aromatic	benzene/sub. benzene	3070	weak
		monosubstituted benzene	700–750 690–710	strong strong
		ortho-disub. benzene	750	strong
		meta-disub. benzene	750–800 860–900	strong strong
		para-disub. benzene	800–860	strong
	alkynes	any	3300	medium
	aldehydes	any	2720 2820	medium
	acyclic C═C	monosub. alkenes	1645	medium
		1,1-disub. alkenes	1655	medium
		cis-1,2-disub. alkenes	1660	medium
		trans-1,2-disub. alkenes	1675	medium
C═C		trisub., tetrasub. alkenes	1670	weak
	conjugated C═C	dienes	1600 1650	strong strong
	with benzene ring		1625	strong
	with C═O		1600	strong
	C═C (both sp^2)	any	1640–1680	medium

Bond	Type of bond	Specific type of bond	Absorption peak (cm^{-1})	Appearance
	aromatic C═C	any	1450 1500 1580 1600	weak to strong (usually 3 or 4)
	C≡C	terminal alkynes	2100–2140	weak
		disubst. alkynes	2190–2260	very weak (often indistinguishable)
C=O	aldehyde/ketone	saturated aliph./cyclic 6-membered	1720	
		α,β-unsaturated	1685	
		aromatic ketones	1685	
		cyclic 5-membered	1750	
		cyclic 4-membered	1775	
		aldehydes	1725	influenced by conjugation (as with ketones)
	carboxylic acids/derivates	saturated carboxylic acids	1710	
		unsat./aromatic carb. acids	1680–1690	
		esters and lactones	1735	influenced by conjugation and ring size (as with ketones)
		anhydrides	1760 1820	
		acyl halides	1800	

Bond	**Type of bond**	**Specific type of bond**	**Absorption peak (cm^{-1})**	**Appearance**
		amides	1650	associated amides
		carboxylates (salts)	1550–1610	
		amino acid zwitterions	1550–1610	
O─H	alcohols, phenols	low concentration	3610–3670	
		high concentration	3200–3400	broad
	carboxylic acids	low concentration	3500–3560	
		high concentration	3000	broad
N─H	primary amines	any	3400–3500	strong
			1560–1640	strong
	secondary amines	any	>3000	weak to medium
	ammonium ions	any	2400–3200	multiple broad peaks
C─O	alcohols	primary	1040–1060	strong, broad
		secondary	~1100	strong
		tertiary	1150–1200	medium
	phenols	any	1200	
	ethers	aliphatic	1120	
		aromatic	1220–1260	
	carboxylic acids	any	1250–1300	
	esters	any	1100–1300	two bands (distinct from ketones, which do not possess a C─O bond)
C─N	aliphatic amines	any	1020–1220	often overlapped
	C═N	any	1615–1700	similar conjugation effects to C═O

Bond	Type of bond	Specific type of bond	Absorption peak (cm^{-1})	Appearance
	C≡N (nitriles)	unconjugated	2250	medium
		conjugated	2230	medium
	R─N─C (isocyanides)	any	2165–2110	
	R─N═C═S	any	2140–1990	
	fluoroalkanes	ordinary	1000–1100	
		trifluromethyl	1100–1200	two strong, broad bands
C─X	chloroalkanes	any	540–760	weak to medium
	bromoalkanes	any	500–600	medium to strong
	iodoalkanes	any	500	medium to strong
N─O	nitro compounds	aliphatic	1540	stronger
			1380	weaker
		aromatic	1520 1350	lower if conjugated
P─C	Organophosphorus compound	aromatic	1440-1460	medium
P─O	phosphorus oxide	bonded	1195-1250	strong
		free	1250-1300	strong

Sources:

- *George Socrates (12 April 2004). Infrared and Raman Characteristic Group Frequencies: Tables and Charts. John Wiley & Sons. pp. 18–. ISBN 978-0-470-09307-8. Retrieved 5 December 2012.*
- *Peter Larkin (25 May 2011). Infrared and Raman Spectroscopy; Principles and Spectral Interpretation. Elsevier. ISBN 978-0-12-386984-5. Retrieved 5 December 2012*

Appendix F: Calculation for Water absorption of Terrazzo Tiles

Water absorption of terrazzo tiles was calculated using the following equation.

$$\textbf{Water absorption}(\mathbf{A}),\% = \frac{\boldsymbol{W}_\mathbf{f} - \boldsymbol{W}_\mathbf{o}}{\boldsymbol{W}_\mathbf{o}} * \mathbf{100} \quad ------- (4)$$

Table 8: Water absorption capacity of terrazzo tiles

Samples Run code	**Samples theckness(mm)**	**Initial weight, Wo(g)**	**Final weight, Wf(g)**	**Water Absorption Percentage (%))**
16	16	945.5	943.8	0.032
15	15	780	780.7	0.09
3	18	1105.8	1106.1	0.027
11	15	918.9	921.5	0.282
17	17	998.8	999.6	0.008
8	17	738	739.5	0.203
1	17	969.4	969.8	0.041
4	14	780.1	780.2	0.013
2	16	933.2	933.4	0.021
12	17	968.4	968.7	0.031
10	16	970	972.1	0.216
14	17	970.9	974.1	0.0329
5	17	977.9	980	0.213
7	16	934	936.5	0.268
13	16	933.4	934.2	0.096
9	17	1015	1017.8	0.276
6	18	1013.4	1013.8	0.039

Example: samples dried initially at 105 oC and for over night have weght of 970.9g and weight after three day fully immersion in tap water were 974.1g. The water absorption capacity of the sample is then,

$$\text{WA}(\%) = \frac{974.1 - 970.9}{970.9} * 100 \quad = \mathbf{0.329}\%$$

In the same way to the above, the water absorption capacity of other 16 samples were calculated and averaged to be 0.11%.

Appendix G: DSC-TGA result for the HDPE plastic waste and for the river sand

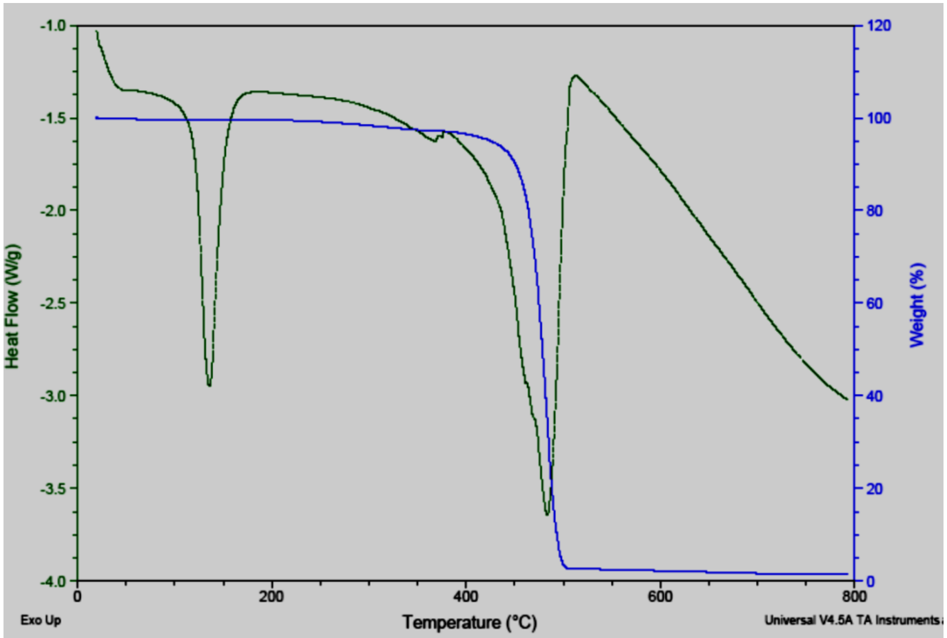

Figure 20: **DSC-TGA result for HDPE waste**

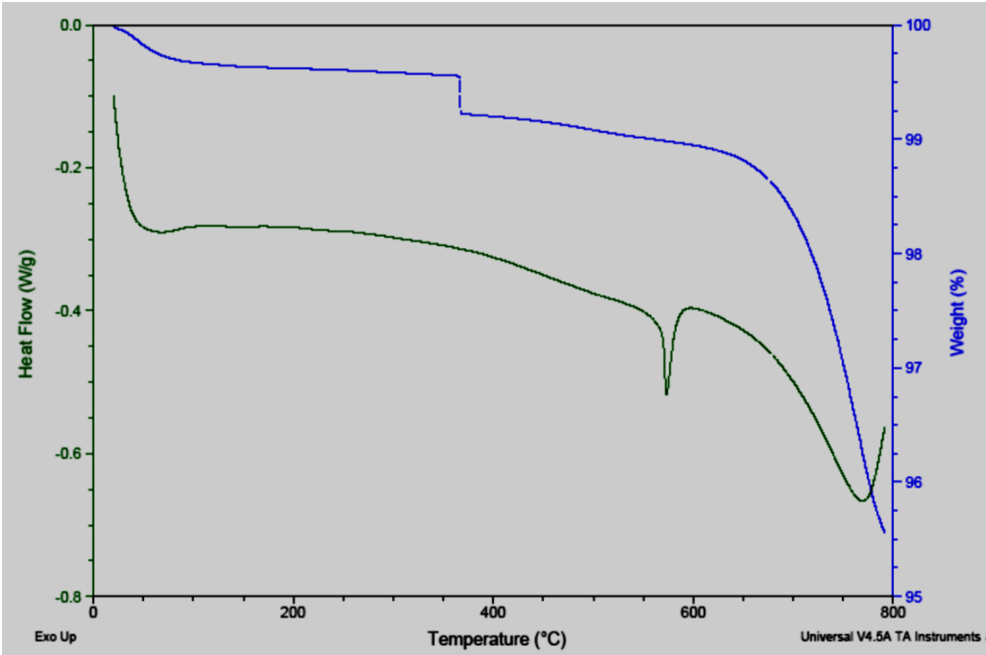

Figure 21 : DSC-TGA result for sand

Appendix H: Statistical tables from design expert

Table 9: lack of fit test

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Linear	78.56	9	8.73	10.98	0.0171	
2FI	73.53	6	12.26	15.42	0.0097	
Quadratic	1.67	3	0.56	0.70	0.5990	Suggested
Cubic	0.000	0				Aliased

Table 10: Sequential Model Sum of Squares

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Mean	4923.21	1	4923.21			
Linear	28.00	3	9.33	1.48	0.2649	
2FI	5.02	3	1.67	0.22	0.8815	
Quadratic	71.86	3	23.95	34.56	0.0001	Suggested
Cubic	1.67	3	0.56	0.70	0.5990	Aliased
Residual	3.18	4	0.80			
Total	5032.94	17	296.06			