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Utilization of Municipal Solid Waste Rejects in Producing Wave Dispersion and Shoreline Erosion Protection Structures (Breakwaters)

BY

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B.Sc. Mechanical Engineering, AUC '96

A thesis submitted in partial fulfillment of the requirements for the degree

of

Master of Science in Engineering

with specialization in

Environmental Engineering

Under the Supervision of

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Spring 2006

The American University in Cairo
School of Sciences and Engineering

Utilization of Municipal Solid Waste Rejects in Producing Wave Dispersion and Shoreline Erosion Protection Structures (Breakwaters)

A Thesis Submitted by
Yasser Mohamed Ibrahim Mohamed

to the Interdisciplinary Engineering Programs

May 4, 2006

in partial fulfillment of the requirements for the degree of

Master of Science in Engineering with Specialization in Environmental Engineering

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Acknowledgment

I would like to dedicate this work to my late brother, Haithem, May God rest his soul – I will always love and miss you. I would also like to dedicate it to my daughter, Hana, my parents, my family, and my beloved wife, Heba.

I would like to thank Dr. Salah El Haggar for his continuous support and guidance through out the work of this thesis, and through out my professional life. I would also like to thank Dr. Emad Imam and Dr. Edward Smith, AUC Professors. I would like to extend my thanks to Dr. Mohamed El Raey for his contribution and supply of the climate change data reports. Cooperation of the Association for the Protection of the Environment is highly appreciated. Needless to acknowledge the efforts of the staff of the mechanical and construction labs, especially Eng. Tamer Bereakah , Eng. Mamdouh Diab, Eng. Khaled Fadel, Mr. Zakareya Taha, Mr. Hamdy Abdel Sattar, Mr. Saaed Aata, and Chemist Ahmed Eid.

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Abstract

The work presented in this thesis is about utilizing municipal solid waste (MSW) rejects in producing wave dispersion and shoreline erosion protection structures to counter the negative impacts of sea level rise.

The tests selected to evaluate the produced samples included physical property tests, accelerated weather tests and environmental tests. The physical property tests included: specific gravity and density, absorption, compression and abrasion, while the accelerated weather tests included wet-dry test and soundness test. In addition to these tests, leachate was analyzed after the samples were immersed in sea water and fresh water for 28 days. The exhaust gases from the mixing furnace – used to produce samples - were also analyzed to ensure compliance with air emission standards. The produced samples consisted mainly of low density polyethylene rejects (garbage bags), thus the results were compared to low and high density polyethylene as well as concrete bricks and tiles.

The produced samples exhibited good floating characteristics at zero percent sand content. The overall characteristics of 40&50% sand content samples were comparable to concrete and superior to polyethylene. The produced material showed excellent reaction to accelerated weather tests. The total percent loss due to abrasion was minimal. Leachate from seawater showed high TDS due to evaporation of water resulting in increased concentration of salt. However, the overall analysis showed no health hazards. The exhaust gas emission parameters were within the air emission standards set by the Egyptian Environmental Law 4/1994.

The MSW rejects could thus be utilized as floating breakwaters using 0% sand content, solid submerged structural breakwaters using 40% sand content, and 50% sand content for beach/canal revetments. Future recommended applications for further investigation could include usage as interlocking ground reinforcement tiles, reef ball and artificial reef.

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List of Abbreviations

APE	Association for the Protection of the Environment
CO2	Carbon Dioxide
EEAA	Egyptian Environmental Affairs Agency
EMS	Environmental Management System
EPA	Environmental Protection Agency
EPDM	Ethylene Propylene Diamine Monomer
GHG	Greenhouse Gases
HDPE	Hight Density Polyethylene
HFC	Hydroflourocarbons
IPCC	Intergovernmental Panel on Climate Change
ISWM	Integrated Solid Waste Management
LDPE	Low Density Polyethylene
MSL	Mean Sea Level
MSW	Municipal Solid Waste
MTCE	Metric Tons of Carbon Equivalent
OECD	Organisation for Economic Co-operation and Development
PE HD	Polyethylene High Density
PE LD	Polyethylene Low Density
PET/PETE	Polyethylene Terephtalate
PFC	Perflurocarbons
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinyl Chloride
SF6	Sulfer Hexafluroide
TCLP	Toxicity Characteristic Leaching Procedure
TTLC	Total Threshold Limit Concentration
WDT	Wave Dispersion Technologies, Inc

CHAPTER ONE

INTRODUCTION

This introductory chapter presents general information about municipal waste, greenhouse gases and climate change. The impacts of climate change and sea level rise are zoned on Africa and Egypt to properly identify the problem and illustrate the need for the work conducted in this thesis.

1.1. Municipal Solid Waste

Improper management of solid waste is a global problem due to its environmental impacts. Solid waste is divided into several categories; the following are the various types of wastes [54]:

§   Municipal Solid Waste (MSW): is typical waste derived from households and commercial venues, including paper, plastic, glass, metal, and organic waste or food remains.

§   Industrial waste is the non hazardous output of industrial operations.

§   Hazardous waste is the hazardous segment of waste resulting from industries of petrochemicals, metal foundries, electroplating, textile mills, etc.

§   Hospital waste.

§   Agricultural waste.

§   Construction debris.

§   Sludge from wastewater treatment plants.

To begin, MSW is the most general type of waste produced by humans on earth. According to the Organization for Economic Co-operation and Development (OECD) Environmental Outlook Report regarding waste, the following represents the composition of the waste sectors in OECD countries[1]. Manufacturing is the major waste constituent at a production rate of 25% followed by agricultural waste at 21%, and then MSW, mining and construction at 14% each, and other minor sources. [72] Presented in the pie chart in Figure 1 is a breakdown of the waste producing sectors.
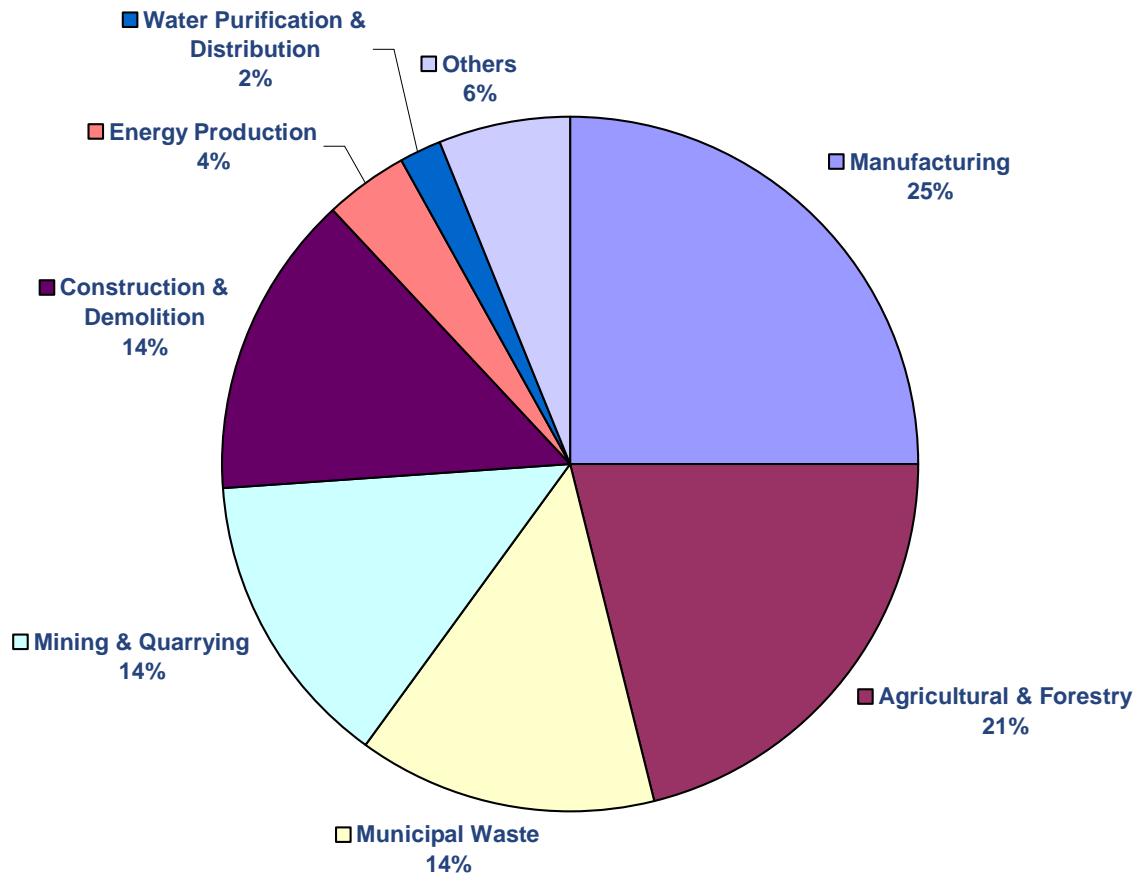
Figure 1: Composition of total waste generated in OECD region [72]

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[1] OECD Countries: Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, the United States, Finland, Australia, New Zealand, Mexico, the Czech Republic, Hungary, Poland, Korea, the Slovak Republic, and the Commission of the European Communities.

However, typical waste composition in Egypt shows that agricultural waste is the largest constituent, while MSW represents 21.5% of the total waste produced [30]. The composition of total waste generated in Egypt is presented in Table 1:

Table 1: Types and Amounts of Solid Waste in Egypt (El-Haggar, 2000) [48]

Type	Average Annual Amount (ton)	Percentage (%)
1. Agricultural waste	23 Million	35
2. Water canals & drain – cleaning waste	20 Million	30.3
3. Municipal waste	14-15 Million	21.5
4. Industrial waste	4-5 Million	6.25
5. Construction & Demolition waste	3-4 Million	4.5
6. Sludge	1.5-2 Million	2.3
7. Hospital waste	100-120 Thousand	0.15
Total	**65.6 -69.1 Million ton**	**100%**

The world is becoming increasingly consumer oriented; and thus, the quantity of waste generated is also rising at an alarming rate. According to the Global Waste Management Market Report, the amount of municipal waste was estimated at about 1.82 billion tons - an increase of 7% on the figures of 2003 [79]. The amount of municipal waste is estimated to rise by 31% in 2008 to reach nearly 2.5 billion tons. [79] This huge amount could cover the total continent of Australia at a thickness of 1 mm. (Calculated at an average density of 0.3 tons/m^3)

1.1.1. MSW Composition

Consumption patterns within any community differ according to social standards and seasons. MSW composition in the United States is diverse. The largest component is paper and paperboard products at a production rate of 35 percent of the waste stream, followed by yard trimmings and food scraps together accounting for about 24 percent. [53] Plastics waste comprises 11 percent of the total MSW; metals make up 8 percent; and rubber, leather and textiles account for about 7 percent. [53]

Wooden waste follows at 6 percent, glass at 5 percent, and other miscellaneous wastes account for approximately 3 percent of the MSW generated in 2003 [53]. A breakdown of the United States MSW materials generated in 2003 is provided in Figure 2.
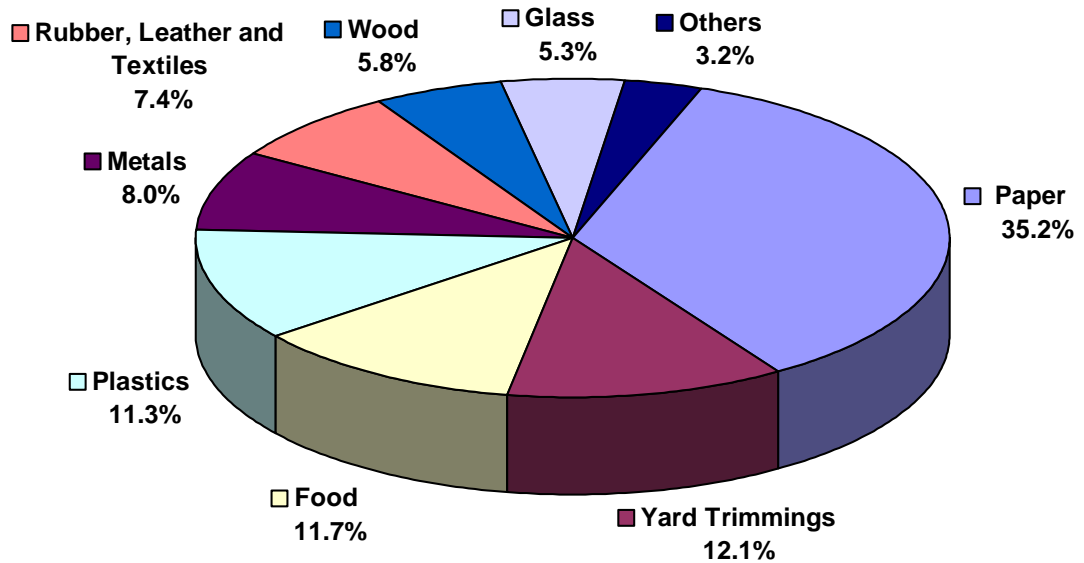
Figure 2: US MSW Composition in 2003 [53]

In comparison to the United States, MSW composition in Egypt is very different: in the US, where wrapping is used a lot, paper constitutes the majority of the waste; by contrast, the MSW composition in Egypt reveals high organic waste content constituting the largest portion of MSW at 60%. Plastic waste in Egypt accounts for 12% of the total MSW produced, paper at 10%, glass, textiles and metals at 3%, 2% and 2% respectively, and others at 11% [30,92]; a breakdown by weight percentage is illustrated in Figure 3.
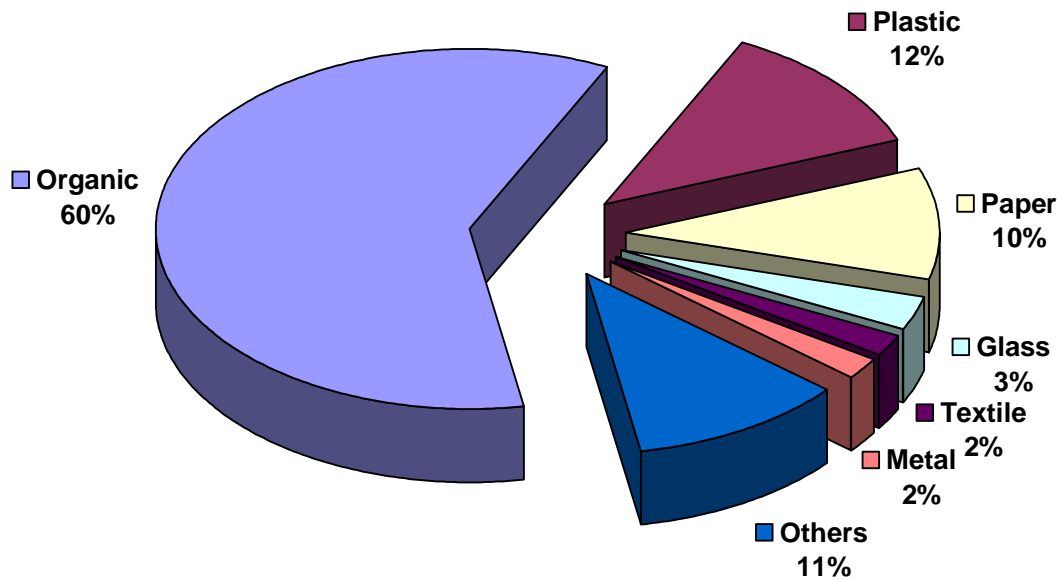
Figure 3: MSW Composition in Egypt [92]

1.1.2. MSW Management

A properly integrated solid waste management (ISWM) system consists of the following steps: [54]

1. Collection: where waste is collected from point source/curbside using trucks or other means of collection/transportation of the waste produced to a transfer station.

2. Transfer: would means that waste collected from various sources (transfer stations) being then transferred to a properly designed landfill. Transfer can be done using trucks, trains, or boats depending on location and system logistics.

3. Sorting: would require differentiating the different type of waste either at point source or at the designated landfill.

ISWM system is affected by several factors. The socio-economic factors include land cost, operational costs, and collection costs; while the demographic factors include accessibility, and collection schemes. The overall service cost determines the success of the system especially in countries newly adopting the system, such as Egypt.

The next phase in an ISWM system includes waste handling after arriving at the treatment facility. The waste is categorized according to the following handling methods: [54]

§ ***Recycling*** recyclables are grouped together according to type and distributed over the allocated stations to manufacture new products.

§ ***Composting*** organic waste utilized to produce compost material (soil conditioner).

§ ***Incineration*** is preferred when hazardous waste is suspected

§ ***Landfilling*** where non recyclable wastes (rejects) end up for dumping.

In the mid-1990s, approximately 64% of municipal waste was destined for landfill, 18% for incineration and 18% for recycling, including composting (OECD, 1999a). Although landfill is still the most widely used method in waste handling, recycling has increased considerably in most OECD countries. [72] Recycling programs have included separate collection and voluntary agreements. Recycling rates for paper/cardboard and glass have increased in most countries. Some countries have introduced the concept of extended producer's responsibility with regard to waste collection and/or recycling of items such as used packaging, batteries and tires. Composting biodegradable waste has become a major option for reducing the total volume of waste sent to disposal.

Incineration of waste is also increasingly used, and energy recovery is gradually becoming an integral part of incineration. [57] In the mid-1990s, over 50% of municipal waste incinerators in OECD regions were equipped with energy recovery systems [72].

Standards for landfilling and incineration have been strengthened in a number of OECD countries. According to the OECD Environmental outlook report of the year 2001, the MSW system is expected to change considerably in the future. The reference scenario projects a significant increase in the share of waste that is diverted to recycling and a decrease in that which is landfilled. In 2020, about 50% of municipal waste is likely to be landfilled, 33% to be recycled and 17% incinerated in OECD regions – compared to 64% landfilled, 18% recycled and 18% incinerated in the mid-1990s [72]. The report highlights the possibility that non-OECD regions are also projected to show significant changes in waste treatment methods, thus landfill is expected to decrease from about 80% in 1995 to about 70% in 2020, and recycling to increase from about 10% in 1995 to about 20% in 2020. The following figure illustrates the ISWM system in OECD and non OECD countries. [72]
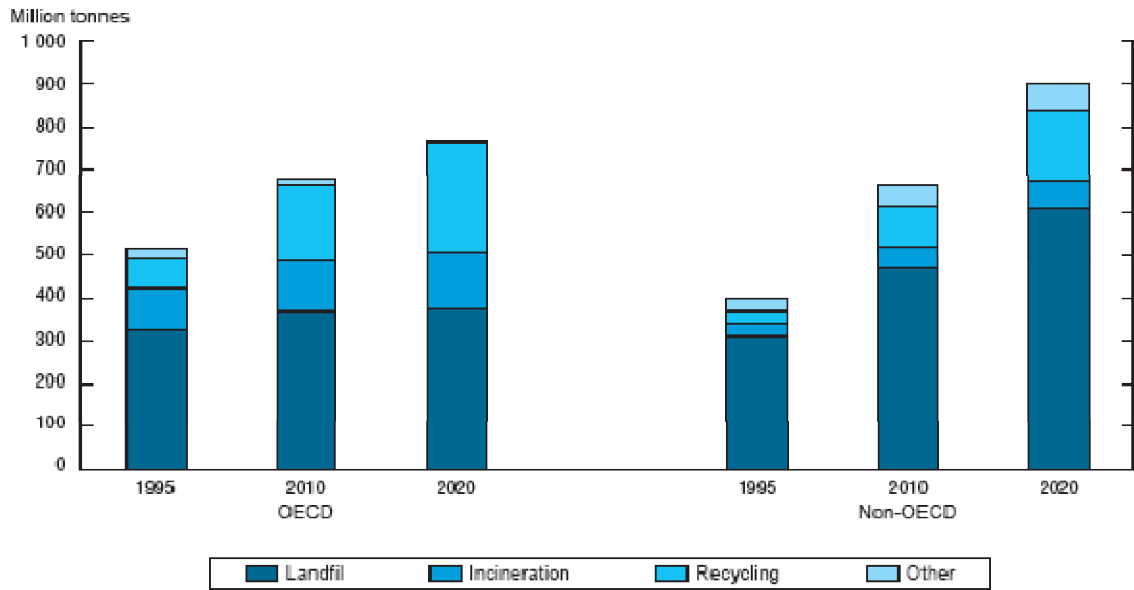
Figure 4: MSW Management 1995-2020 [72]

1.1.3. MSW and Environment

Municipal solid waste is a concern not only because it means increase in depletion of resources, but also because it contributes to environmental pollution and health problems. MSW adversely impact the environment in the following manner [50].

1. Airborne pollution through exhaust from collection trucks or open-burning in dump sites or incineration

2. Health risk impact due to enhancing the growth of bacteria, flies and rodents in dump sites

3. Release of greenhouse gases (GHGs) into the atmosphere through methane release or carbon dioxide from emissions

4. Groundwater contamination from uncontrolled leachate in dump sites

In addition, landfilling is not the best utilization practice for land space.

1.1.4. Recycling and Environment

The 3 "R's" for waste management are: reduction, reuse and recycling. Waste prevention and recycling contributes to environment protection and results in the following:

§ ***Reduction of emissions from energy consumption***. Recycling saves manufacturing energy. Recycled products typically require less energy than production from virgin materials. With reuse, less energy is needed to extract, transport and process raw materials and to manufacture products. Accordingly, energy demand decreases and fewer fossil fuels are burned, thus less carbon dioxide is emitted to the atmosphere. [50]

§ ***Reduction of emissions from incinerators***. Directing the waste to recycling results in reducing the amounts incinerated. Thus GHGs emissions from the combustion of waste as well as airborne emissions are reduced. [50]

§ ***Reduction of methane emissions from landfills***. Organic wastes produce methane gas while decomposing; accordingly, reducing the waste result in reduction of methane release. [50]

§ ***Increase of carbon storage in trees***. Trees absorb carbon dioxide from the atmosphere and store it in wood, in a process called "carbon sequestration." Waste prevention and recycling of paper products result in preserving trees in forests, where removal of carbon dioxide from the atmosphere is achieved. [50]

Figure 5 illustrates the link between waste management and greenhouse gases:
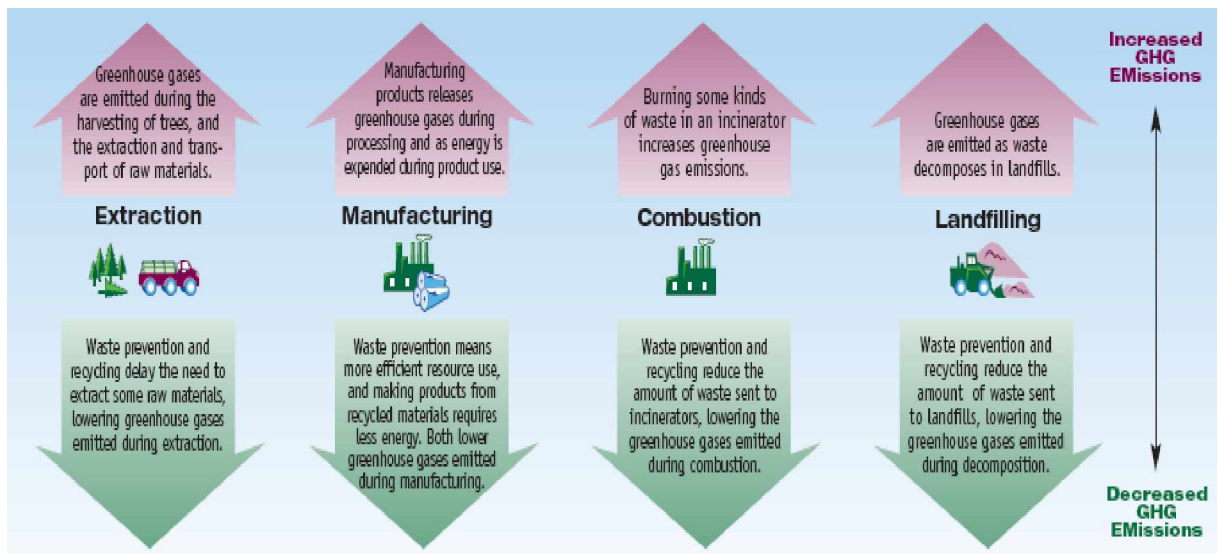
Figure 5: Waste Management and Greenhouse Gases [50]

The above figure shows the activities of extraction, manufacturing, combustion and landfilling in relation to rate of GHGs emissions. During raw material extraction and manufacturing processes, GHGs are generated either during transportation, processing, or energy usage; however, recycling would decrease the need for raw material extraction, transportation and production, thus ultimately decreasing GHG emissions. Decrease in waste incineration and landfilling activities results in decreasing the GHG emissions, because waste prevention and recycling reduce waste sent hence incinerated or landfilled.

According to a research done by the US Environmental Protection Agency (EPA), "cutting the amount of waste generated in the US back to 1990 levels, greenhouse gas emissions could be reduced by 18 million metric tons of carbon equivalent (MMTCE) - the basic unit of measure for greenhouse gases. EPA estimates that increasing national recycling rate from 30 percent in 2000 to 35 percent would reduce greenhouse gas emissions by another 10 MMTCE, compared to landfilling the same material. Together, these levels of waste prevention and recycling could be

comparable to annual emissions from the electricity consumption of nearly 4.9 million households. For example, an office building of 7,000 workers could reduce GHG emissions by 570 metric tons of carbon equivalent (MTCE) by recycling all of its office paper waste for one year. This is the equivalent to taking about 370 cars off the road that year." [50]

1.2. Greenhouse Gases & Climate Change

1.2.1. Greenhouse Gases

The atmosphere that surrounds the Earth consists of various types of gases, including those known as "greenhouse gases". Some GHGs occur naturally in the atmosphere, while others are results from human activities. Naturally occurring GHGs include water vapor, carbon dioxide, methane, nitrous oxide, and ozone. However, industrial operations increased the atmospheric concentration levels of most of these naturally occurring gases, such as:

§ *Carbon dioxide* is released to the atmosphere when solid waste, fossil fuels (oil, natural gas, and coal), and wood and wood products are burned. [56]

§ *Methane* is emitted during the production and transportation of coal, natural gas, and oil; the decomposition of organic wastes in MSW landfills; and the raising of livestock. [56]

§ *Nitrous oxide* is emitted during agricultural and industrial activities, as well as during the combustion of solid waste and fossil fuels. [56]

Several classes of halogenated substances resulting from industrial activities are classified as GHGs, such as:

§ *Hydroflurocarbons (HFC*s) emissions include foams, refrigeration, air-conditioning, solvents, aerosols, and fire extinguishing sectors. [56]

§ *Perfluorocarbons (PFCs)* and *Sulfur Hexafluoride (SF6)* are predominantly emitted from industrial processes, including magnesium casting, aluminum smelting, semiconductor manufacturing, and electric power transmission and distribution systems. [56]

Greenhouse gases (GHG) absorb and retain heat from the sun thus regulating the Earth's climate by holding warmth in an atmospheric blanket around the planet's surface in a phenomenon called the "greenhouse effect". According to various scientists, the average temperature on Earth would be less by 2 degrees if GHGs were not emitted from the first place. [50] In the past 100 years, scientists have detected an increase of 1 degree in the Earth's average surface temperature. [50]

GHGs adversely impact life on earth, disrupt the diversity of habitats and the life dependent on them. In particular, health, agriculture, water resources, forests, wildlife, and coastal areas are vulnerable to the changes that global warming may bring, the following is a foreseen result of an increase of few degrees in the Earth's average temperature: [50]

§ Increased rate of glacial melting causing rise in sea level.

§ More frequent and intense storms and hurricanes.

§ Flooding of beaches, bay marshes, and other low-lying coastal areas.

§ More precipitation in some areas and not enough in others.

§ Wider distribution of certain infectious diseases.

Such significant changes could damage communities and national economies. Climate change will not be easily reversed because GHGs remain in the atmosphere for a long time; turning back climate change may take decades or even centuries. [50, 28]

1.2.2.   Global Warming & Sea Level Rise

"The concentration of CO_2 in the earth's atmosphere has increased by about 25% over the past century". [81] In addition to trace gases, aerosols, etc. those have caused an increase of $0.5^{o}C$ in the northern hemisphere. "The general worming trend will lead to a rise in sea levels owing to thermal expansion of the ocean's water and to a melting of glacial snow and ice". [81]

The change in weather patterns would result in greater difference in winter and summer, and more temperature differentials at the poles to the equator resulting in "less vigorous ocean currents and continental weather system".[81] Warming of poles means less rate of over water dissipation and more ability of hurricane/monsoon traveling away from the equator. "Reduced sea ice will result in larger fetches for wave generation in polar latitudes and longer periods of shoreline exposure to wave attack". [81]

"Since records indicate that CO_2 concentration in the atmosphere are not only increasing, but at an accelerating rate, strong concern has developed during the past decade that eustatic sea level rise might also accelerate and become a significant future problem. Assuming a reasonable temperature rise and including the effects of oceanic thermal expansion and melting of Greenland and mountain glaciers, Revelle

estimated a 700 mm (2.3 ft) eustatic sea level rise by the year 2075."[81] The table below presents the different scenario for estimates of sea level rises.

Table 2: Estimates Sea Level Rise, 2000-2100, by Scenario (in cm, with inches in parentheses) [81]

Year	Mid-Range Scenarios			High Scenario	Historical Extrapolation
	Conservative	Moderate	High		
2000	4.8	8.8	13.2	17.1	2-3
	(1.9)	(3.5)	(5.2)	(6.7)	(0.8-1.2)
2025	13.0	26.2	39.3	54.9	4.5-8.25
	(5.1)	(10.3)	(15.5)	(21.6)	(1.8-3.2)
2050	23.8	52.3	78.6	116.7	7-12
	(9.4)	(20.6)	(30.9)	(45.9)	(2.8-4.7)
2075	38.0	91.2	136.8	212.7	9.5-15.5
	(15.0)	(35.9)	(53.9)	(83.7)	(3.7-6.1)
2100	56.2	144.4	216.6	345.0	12-18
	(22.1)	(56.9)	(85.3)	(135.8)	(4.7-7.1)

"Stone mound groins and breakwaters, concrete seawalls and piers have design live of about 50 years or longer".[81] The impact of sea level rise on coastal structures is related to the design of wave height "limited by the wave breaking depth just seaward of the structure". [81] "A rise in sea level not only moves MSL line landward due to increased water level flooding further up the beach; but there is also an adjustment of the equilibrium shore profile resulting in beach erosion owing to the movement of sand from the beach face to offshore". [81]

1.3. Climate Change Impact on Africa

According to a report by the Intergovernmental Panel of Climate Change (IPCC) in 1997, under doubled CO_2 concentrations, climate change is projected to adversely affect several physical, ecological/biological, and socioeconomic characteristics of the West African coastal zone and adjacent oceans that presently are under stress.[87] At the same time, population pressures and conflicting policies of exploitation of coastal resources also have had adverse effects on coastal sustainability. Environmental problems degrading coastal areas are projected to

increase as a result of either sea-level rise or an increase in extreme weather events.
[87]

1.3.1.   African Coastal Zones

Climate change will aggravate existing physical, ecological, and socioeconomic stresses on the African coastal zone. Sea level rise would erode low-lying areas or increase flooding caused by storm surges and intense rainstorms. [87] The coastal nations of west and central Africa (e.g., Senegal, The Gambia, Sierra Leone, Nigeria, Cameroon, Gabon, Angola) have low-lying lagoon coasts that are being threatened by the sea level rise as their coastal developed cities are susceptible to erosion. [87]

"Africa's west coast often is buffeted by storm surges and currently is at risk from erosion, inundation, and extreme storm events. Inundation could be a significant concern (Awosika et al., 1992; Dennis et al., 1995; French et al., 1995; ICST, 1996; Jallow et al., 1996). Major cities such as Banjul (Jallow et al., 1996), Abidjan, Tabaou, Grand Bassam, Sassandra, San Pedro (ICST, 1996), Lagos, and Port Harcourt (Awosika et al., 1992)-all situated at sea level-would be very vulnerable. Finally, tidal waves, storm surges, and hazards also may increase and may modify littoral transport (Allersman and Tilsmans, 1993)". [87]

Unlike western Africa's Atlantic Coast, the coastal zone of east Africa is expected to be less affected as the area experiences calm conditions through much of the year. Along the east coast of Africa, sea-level rise and climatic variation may decrease the attenuation of coral and patch reefs that have evolved along major sections of the continental shelf. The lessening of this buffer effect as a result of

climate change would increase the potential for erosion of the east coast. Increases in population growth rates in the principal coastal cities of east Africa, combined with a likelihood of a 1-m sea-level rise, could create conditions for significant negative impacts on tourism-oriented economies, ecology, and natural habitats of this area. [87]

1.3.2. Sea Level Impact on Egypt

"Results from studies on various aspects of the impacts and possible responses to sea-level rise on the Egyptian coast (Broadus et al., 1986; Milliman et al., 1989; Sestini, 1989; Ante, 1990; El-Raey, 1990; El-Sayed, 1991; Khafagy et al., 1992; Stanley and Warne, 1993) indicate that a sizable proportion of the northern part of the Nile delta will be lost to a combination of inundation and erosion, with consequent loss of agricultural land and urban areas. Furthermore, agricultural land losses will occur as a result of soil salinization." [49]

"With an estimate of 1-m sea-level rise, about 2,000 Km^2 of land in coastal areas of the lower Nile delta may be lost to inundation. Substantial erosion should be expected, possibly leading to land losses of as much as 100 Km^2. A very rough estimate of the agricultural land area that might become unusable is 1,000 Km^2 (100,000 ha). Outside the delta, erosion is expected to be quite limited." [49]

As for the Governorate of Alexandria, two main economic areas appear most vulnerable: the Alexandria lowlands and the Alexandria beaches. [49] The Alexandria lowlands, where the main development took place, are vulnerable to inundation, water logging, increased flooding, and salinization under accelerated sea-level rise. "The two surviving Alexandria beaches (Gleam and El Chatby) will be lost even with a 0.5-m rise in sea level." [49] "An average business loss is estimated at US$127 million/yr

because most tourist facilities such as hotels, camps, and youth hotels are located within 200-300 m of the shoreline" [49]. "It has been widely reported that 8 million people would be displaced in Egypt by a 1-m rise in sea level, assuming no protection and existing population levels". This estimate is based on the displacement of 4 million people in the Nile delta, as well as the entire population of Alexandria. [47, 49]

1.4. Problem Identification & Objectives

As illustrated throughout this chapter, a link between mismanagement of municipal solid wastes, global warming and sea level rise could be vividly demonstrated. Although recycling is being imposed and favored throughout the globe, there still exist some rejects that could not be recycled. This thesis hence aims at utilizing the municipal solid waste rejects in producing wave dispersion and shoreline erosion protection structures (breakwaters). The product is to be tested in accordance to specifications to ensure its suitability for the intended function (breakwaters) to counter the impacts of sea level rise.

1.5. Thesis outline

In the next chapter, more details regarding recycling technologies worldwide will be presented with a focus on recycling programs in Egypt. Followed by highlights from the literature survey regarding shoreline erosion protection structures (breakwater), history and design of armor units, new developments in structure and material.

In chapter three, tests selection criteria are presented. In addition to description of the experimental facilities, machine settings, experimental procedures, and sample production.

The results are presented in chapter four. Analysis of the results in comparison to specifications and in accordance to the required function is also included within the context of the chapter. Then the proposed product properties are compared to polyethylene and concrete.

In chapter five, a summary of the major findings through out this work is presented as well as the final conclusions regarding the usage of MSW reject material. Chapter five also includes recommendations regarding additional applications and possible modifications that should be further investigated.

CHAPTER TWO

LITERATURE SURVEY

2.1. Recycling

The handling of waste in an ISWM system includes recycling at one stage, where recyclable materials are sorted and processed/manufactured into new products.

Collecting and processing secondary materials, manufacturing recycled-content products, and then purchasing recycled products is the supreme target loop which ensures the success of a recycling program. Effective and successful recycling program would require the following:

1. **Collection and Processing** [51]: Collecting recyclables via the methods of curbside, drop-off centers, buy-back centers, and deposit/refund programs. Recyclables are then sent to a materials recovery facility to be sorted and prepared into marketable commodities for manufacturing.

2. **Manufacturing** [51]**:** Once cleaned and separated, the recyclables are ready to undergo the second step of a recycling program to be manufactured with total or partial recycled content. Common household items that contain recycled materials include newspapers and paper towels; aluminum, plastic, and plastic bottles, glass containers; and steel cans. Recycled materials also are used in innovative applications such as recovered glass in roadway asphalt (glassphalt) or recovered plastic in carpeting, park benches, and pedestrian bridges.

3. **Purchasing Recycled Products** [51]: Purchasing recycled products completes a successful recycling program. As consumers demand more environmentally sound products, manufacturers will continue to meet that demand by producing high-quality recycled products

"In 1999, recycling and composting prevented over 60 million tons of materials from ending up in landfills. Today, the U.S. recycles over 28% of all its wastes, a number which has doubled in the past fifteen years. 42% of all paper, 40% of all plastic bottles, 55% of all drink cans, 57% of all steel packaging and 52% of all major appliances are now recycled." [53] Table 3 shows the types of materials in MSW, their generations and recovery amounts and percents as per EPA 2003 report.

Table 3: Generation and Recovery of Materials in MSW, US 2003 [53]

	Weight Generated (million tons)	Weight Recovered (million tons)	Recovery as Percent of Generation
Paper and Paperboard	83.1	40	48.1%
Glass	12.5	2.35	18.8%
Metals			
Steel	14	5.09	36.4%
Aluminum	3.23	0.69	21.4%
Other non ferrous metals	1.59	1.06	66.7%
Plastics	26.7	1.39	5.2%
Rubber and Leather	6.82	1.1	16.1%
Textiles	10.6	1.52	14.3%
Wood	13.6	1.28	9.4%
Other Materials	4.32	0.98	22.7%
Other Wastes			
Food, other	27.6	0.75	2.7%
Yard Trimmings	28.6	16.1	56.3%
Miscellaneous inorganic wastes	3.62		less than 0.05%
Total MSW	**236.28**	**72.31**	**30.6%**

Plastic recycling figure is noted to be the second least after food and remains from composting.

2.1.1. Plastic Recycling Program

"Plastic recycling is still a relatively new and developing field of recycling. The post consumer items made from PET and HDPE resins have found reliable markets within the US and in Asia." [37] Applications for recycled plastics are growing every day. Plastics can be blended with virgin plastic to reduce cost without sacrificing properties. [37] Recycled plastics are used to make polymeric timbers for use in picnic tables, fences, and outdoor toys, thus saving natural lumber. Plastic from 2-liter bottles is even being spun into fiber for the production of carpet.

Presented in Table 4 an overview of the different post consumer resins, their properties and products.

Table 4: Plastic Resins Codes, Properties and Products [5]

Code	Properties	Products	Products with Recycling Content
PETE Polyethylene Terephthalate (PET, PETE)	Clarity, strength, toughness, barrier to gas and moisture, resistance to heat	Plastic soft drinks, water, sports drink, mouthwash, ketchup, Salad dressing bottles. Peanut butter, pickle, jelly and jam jars. Oven film and oven prepared food trays	Fiber, clothing, film and sheet, food and beverage containers, carpet, strapping, fleece wear, luggage and bottles.
HDPE High Density Polyethylene (HDPE)	Stiffness, strength, toughness, resistance to chemicals and moisture, permeability to gas, ease of processing, and ease of forming	Milk, water, juice, cosmetic, shampoo, dish and laundry detergent bottles; yogurt and margarine tubs; cereal box liners; grocery, trash and retail bags.	Liquid laundry detergent, shampoo, conditioner and motor oil bottles; pipe, buckets, crates, flower pots, garden edging, film and sheet, recycling bins, benches, dog houses, plastic lumber, floor tiles, picnic tables, fencing.

Code	Properties	Products	Products with Recycling Content
3 V **Polyvinyl Chloride (PVC/Vinyl)**	Versatility, clarity, ease of blending, strength, toughness, resistance to grease, oil and chemicals. Stable electrical properties	Clear food and non-food packaging, medical tubing, wire and cable insulation, film and sheet, construction products such as pipes, fittings, siding, floor tiles, carpet backing and window frames.	Packaging, loose-leaf binders, decking, paneling, gutters, mud flaps, film and sheet, floor tiles and mats, resilient flooring, cassette trays, electrical boxes, cables, traffic cones, garden hose, mobile home skirting.
4 LDPE **Low Density Polyethylene (LDPE)**	Ease of processing, strength, toughness, flexibility, ease of sealing, barrier to moisture. Relative transparency	Dry cleaning, bread and frozen food bags, squeezable bottles, e.g. honey, mustard. Film applications	Shipping envelopes, garbage can liners, floor tile, furniture, film and sheet, compost bins, paneling, trash cans, landscape timber, lumber
5 PP **Polypropylene (PP)**	Strength, toughness, resistance to heat, chemicals, grease and oil, versatile, barrier to moisture. High melting point	Catsup bottles, yogurt containers and margarine tubs, medicine bottles	Automobile battery cases, signal lights, battery cables, brooms, brushes, ice scrapers, oil funnels, bicycle racks, rakes, bins, pallets, sheeting, trays.
6 PS **Polystyrene (PS)**	Versatility, insulation, clarity, easily formed Relatively low melting point	Compact disc jackets, food service applications, grocery store meat trays, egg cartons, aspirin bottles, cups, plates, cutlery.	Thermometers, light switch plates, thermal insulation, egg cartons, vents, desk trays, rulers, license plate frames, foam packing, foam plates, cups, utensils
7 OTHER	Dependent on resin or combination of resins.	Three and five gallon reusable water bottles, some citrus juice and catsup bottles.	Bottles, plastic lumber applications.

Plastics are recycled in a number of different ways, presented hereafter is a brief of the recycling techniques of most plastic resins:

Poly Ethylene Terepthalate (PET)

It is a form of polyester or Mylar that is extremely tough and useful. Recycling process of PET is similar to that of the polyethylene. Bottles may be color sorted and are ground up and washed. Unlike polyethylene, PET sinks in the wash water while the plastic caps and labels are floated off. The clean flake is dried and often repelletized. [37]

Recycled PET has many uses and there are well established markets for this useful resin. By far, the largest usage is in textiles. Carpet manufacturing companies can often use 100% recycled resin to manufacture polyester carpets in a variety of colors and textures. PET is also spun like cotton candy to make fiber filling for pillows, quilts and jackets. PET can also be rolled into clear sheets or ribbon for VCR and audio cassettes. In addition a substantial quantity goes back into the bottle market.[37] China is currently using it in the manufacturing process of fiber optics.

According to **Connecticut Metal Industries Inc.** [37] PET prices vary widely with supply; the range is between $0.06 and $0.17 US per pound in 2001.

High Density Polyethylene HDPE

It is a denser form of polyethylene that is almost as dense as water. In recycling, it is broken down into small flakes about 3/8 of an inch (1 cm), which are washed and floated to remove any heavy (sinkable) contaminants. This cleansed flake is then dried in a stream of hot air and may be boxed and sold in that form. More sophisticated plastic plants may reheat these flakes, add pigment to change the color

and run the material through a pelletizer that forms little beads of plastic to be reused in injection molding processes to create new products. [37]

Some common end uses for recycled HDPE are plastic pipes, lumber, flower pots, trash cans, or formed back into non food application bottles.

According to **Connecticut Metal Industries Inc.** [37] the HDPE is relatively low in value, and is being purchased between $0.06 and $0.15 US per pound in 2001

Low Density Polyethylene LDPE

It is chemically similar to HDPE but it is less dense and more flexible. Recycling of LDPE is very similar to HDPE except special grinders are used to handle the thin films which are often washed and repelletized or used directly to make new products. [37]

Some end uses for recycled LDPE are plastic trash bags and grocery sacks, plastic tubing, agricultural film, and plastic lumber.

LDPE is relatively low in value, and according to **Connecticut Metal Industries Inc.** [37] the purchase price is in between $0.01 and $0.15 US per pound in 2001

2.1.2. Green Plastics (Bioplastics)

The new generation of biodegradable plastics is called Bioplastics, whose components are derived entirely or almost entirely from renewable raw materials. Recent advances in research and technology have shown that plastics can be made from abundant agricultural resources thus preserving nonrenewable resources. [82]

Some biopolymers already occur in nature, such as carbohydrates and proteins. Many biopolymers are also produced commercially. Manufacturers are urged to utilize biopolymers in the production of plastics thus decreasing dependence on non-renewable resources. Examples of biopolymers are given below [82]:

§ **Cellulose** a carbohydrate constituting 40% within any organic matter.

§ **Starch** found in corn (maize), potatoes, wheat, tapioca (cassava), and some other plants, is used for non-food purposes, such as manufacturing of paper, cardboard, textile sizing, and adhesives.

§ **Collagen** is the most abundant protein found in mammals. Gelatin is denatured collagen, and is used in sausage casings, capsules for drugs and vitamin preparations, and other miscellaneous industrial applications including photography.

§ **Casein**, commercially produced from cow's skimmed milk, is used in adhesives, binders, protective coatings, and other products.

§ **Soy protein & Zein** (from corn) are abundant plant proteins used for making adhesives and coatings for paper and cardboard.

§ **Polyesters** are produced by bacteria, commercially produced through fermentation processes and used in biomedical applications.

§ **Lactic Acid** commercially produced on large scale through fermentation of sugar feed stocks, or from the conversion of starch from corn, potato peels, or other starch sources. It can be polymerized to produce poly (lactic acid) to be used in drug encapsulation and biodegradable medical devices.

§ **Triglycerides** can also be polymerized. Triglycerides make up a large part of the storage lipids in animal and plant cells.

These natural raw materials are abundant, renewable, and biodegradable, making them attractive feed stocks for bioplastics. Starch-based bioplastics can be processed by all of the methods used for synthetic polymers, like film extrusion and injection molding producing eating utensils, plates, and cups. Soybeans could be processed with modern extrusion and injection molding methods. Many water soluble biopolymers when properly plasticized have potential use as non-supported stand-alone sheeting for food packaging and other purposes. Starch-protein compositions meet nutritional requirements for farm animals. If starch-protein plastics were commercialized, used food containers and services ware collected from fast food restaurants could be pasteurized and turned into animal feed. [82]

Polyesters are now produced from natural resources-like starch and sugars-through large-scale fermentation processes, and used to manufacture water-resistant bottles, eating utensils, and other products. Poly (lactic acid) used for recyclable and biodegradable packaging, such as bottles, yogurt cups, and candy wrappers, is also used for food service ware, lawn and food waste bags, coatings for paper and cardboard, and fibers-for clothing, carpets, sheets and towels, and wall coverings. In biomedical applications, it is used for sutures, prosthetic materials, and materials for drug delivery. [82]

Triglycerides are being studied with composites as glass fiber reinforcement to be used in applications such as manufacturing of agricultural equipment, automotive industry, construction, and other areas. [82]

The widespread use of these new plastics will depend on developing successful technologies in the marketplace. That in turn will partly depend on

commitment of societies to the concepts of resource conservation, environmental preservation, and sustainable technologies. If so, "bioplastics will find a place in the current age of plastics". [82]

2.1.3. Recycling in Egypt

Waste in Egypt is collected via an informal sector known as Zabaleen. The collectors manage to divert 80-85% of household waste away from landfills.[48] Waste is sorted and items are either sold to recyclers to be reprocessed or recycled by the Zabaleen themselves if they own small recycling machines from external donations or loans, while the remaining garbage is dumped into a landfill. [92] Recycling of MSW constituents is conducted in the following manner:[2]

Food Residues & Organic Matter

Organic matter - as illustrated in Chapter 1 - is the highest constituent of the collected municipal waste in Egypt. The Zabaleen give it to pigs and goats, and then send the mixed pig manure with the remaining organic waste for composting. Figure 6 shows a composting plant in APE where organic remains are being laid on the ground and open air for about 2 months to compost.

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[2] Based on a visit to the **Association for the Protection of the Environment (APE)** Plant in Al Kattamia, Ein El Sokhna Highway, Cairo

Figure 6: Composting in APE

<u>**Paper**</u>

Paper is collected for recycling in accordance to the following steps:

1. Thickening by adding water: paper is thickened to produce paper pulps.

2. Pilling of paper onto several layers.

3. Coloring and layers press.

4. Drying in the sun.

Products from recycled paper presented in Figure 7 include cards, bags, etc.

Figure 7: Sample of paper products produced from recycling

<u>**Textile**</u>

Rags from textile factories are sorted for recycling. As shown in Figure 8, female workers sort the rags according to colors, which are then used in producing rugs, bags, and patchwork through using looms and sewing kits. Some factories use the rags in producing new look outfits, but that is rather dependable on the plants' Environmental Management System.

Figure 8: Sorting of rags according to color before rug making

Plastic

Plastic is recycled to produce different plastic products like cloth hangers, garbage plastic bags, construction joints, etc. The recycling program includes:

1. HDPE and LDPE palletizing,
2. PP injection molding
3. PVC hose manufacturing
4. PET recycling
5. LDPE garbage film bags

Pictures presented hereafter are captured from the **APE** recycling plant. Figure 9 shows a PE pellet machine, where plastic waste is collected and being fed to the machine to produce long wires that are cut to result in small powder like pellets.

Figure 9: Pellet Machine

Figure 10 shows a plastic injection molding machine, where PP is being fed and heated then pressed to a mold to produce a specific product.

Figure 10: Injection Molding Machine

Figure 11: Hose Manufacturing Machine

Figure 11 illustrates a hose manufacturing machine (not working while visit), plastic pellets are heated to produce PVC hoses.

Figure 12: Horizontal axis shredder used for hard plastic

Figure 12 shows an axial shredder machine, where plastic passes through horizontal stationary and rotating knives to produce small plastic pieces used in most processing machines.

Figure 13: Agglomerating machine for thin film plastic

Thin film plastic is fed into an agglomeration machine shown in Figure 13, which operates in a similar manner as the horizontal shredder, but the knives are set on rotating plate on the base of the machine. Along with the rotating knives, stationary ones are attached to the sides of the machine. The agglomerated plastic is small shredded pieces that are being used as raw material in other manufacturing processes.

Figure 14: PET Floatation Tank

The plastic PET bottles are being shredded and set into a floatation tank (Figure 14), that is being monitored for contaminants removal; PET is then exported to China to be used in manufacturing of fiber optic cables.

Figure 15: Film machine that converts LDPE into garbage plastic bags

Shredded fine particles plastic is fed to the machine in Figure 15 to be heated and left to flow acted by the gravitational force to produce film sheets which are then sealed and double sealed to produce LDPE garbage bags.

The wastes produced from plastic bags are not made of the same plastic resin and are virtually impossible to sort using the current processing technology (manual sorting). Plastic bags wrap themselves around the conveyor belt rollers and damage plants' processing equipment. Accordingly, they pose a processing problem in an ISWM program. In addition to the dirty/contaminated condition, waste generated from plastic bags is not applicable to most recycling programs. [34]

As mentioned in Chapter 1, the objective of this thesis is to utilize the waste rejects consisting mainly of plastic garbage bags in producing shoreline erosion protection structures (breakwaters), accordingly, the next section in the literature survey would be an introduction to breakwaters, history and design of armor units, new developments in structure and material for coastal zone protection.

2.2. Shoreline Erosion Protection Structures

Shoreline erosion protection structures vary in shape, function and design. The types of shore protection structures are as follows:

- § *Seawalls:* are usually massive, vertical structures used to protect backshore areas from heavy wave action, and in lower wave energy environments, to separate land from water. [31]

- § *Bulkheads:* are vertical retaining walls to hold or prevent soil from sliding seaward. [31]

- § *Dikes and Levees:* are earth structures (dams) that keep elevated water levels from flooding interior lowlands. [31]

- § *Sills/Perched Beaches:* used to trap sand resulting in what is known as a "perched beach," one that is elevated above its original level. [31]

- § *Jetties and Piers:* are shore-normal structures commonly used for training navigation channels and stabilizing inlets. [31]

- § *Groins:* are the oldest and most common shore-connected, beach stabilization structures. [31]

- § *Revetments:* are covers or facing of erosion resistant material placed directly on an existing slope, embankment or dike to protect the area from waves and strong currents. [31]

- § *Breakwaters:* are generally shore-parallel structures that reduce the amount of wave energy reaching a protected area. [31]

Figure 16: Photos of Floating Breakwater (*Left*) and Revetment (*Right*)

Figure 16 shows a series of floating breakwater units and revetment units for usage as shoreline erosion protection structures. Breakwaters are built to reduce wave action through a combination of reflection and dissipation of incoming wave energy. When used for harbors, breakwaters are constructed to create sufficiently calm waters for safe mooring and loading operations, handling of ships, and protection of harbor facilities. Breakwaters are also built to improve maneuvering conditions at harbor entrances and to help regulate sedimentation by directing currents and by creating areas with differing levels of wave disturbance. Protection of water intakes for power stations and protection of coastlines and beaches against tsunami waves are other applications of breakwaters. [31]

When used for shore protection, breakwaters are built in near-shore waters and usually oriented parallel to the shore like detached breakwaters (shown in Figure 17). The layout of breakwaters used to protect harbors is determined by the size and shape of the area to be protected as well as by the prevailing directions of storm waves, net direction of currents and littoral drift, and the maneuverability of the vessels using the harbor. Breakwaters protecting harbors and channel entrances can be either detached or shore-connected. [31]

Figure 17: Breakwaters in Alexandria

"The cost of breakwaters increases dramatically with water depth and wave climate severity. Also poor foundation conditions significantly increase costs. These three environmental factors heavily influence the design and positioning of the breakwaters and the harbor layout." [89]

Breakwaters can be classified into two main types:

1. Sloping-Front Structures: rubble-mound structures armored with rock or concrete armor units, with or without wave-wall superstructures.

2. Vertical-Front Structures: constructed of either sand filled concrete caissons or stacked massive concrete blocks placed on a rubble stone bedding layer.

In deep water, concrete caissons are often placed on a high mound of quarry rock for economical reasons. These breakwaters are called composite structures. The upper part of the concrete structure might be constructed with a sloping front to reduce the wave forces as shown in Figure 18. Front wall might be perforated with a wave chamber behind to dissipate wave energy as in Figure 19. Smaller vertical structures might be constructed of steel sheet piling backfilled with soil or built as a rock-filled timber cribwork or wire cages as in Figure 20. In milder wave climates batter piles could be used to support sloping reinforced concrete slabs. [31]
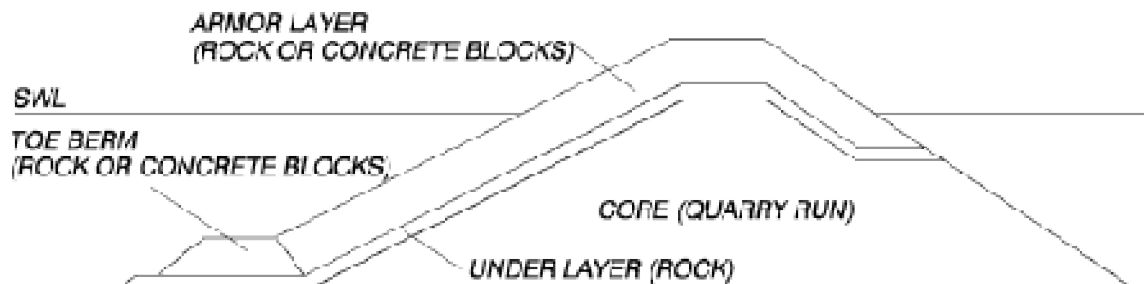
Figure 18: Conventional Multi-Layer Rubble Mound Breakwater [31]
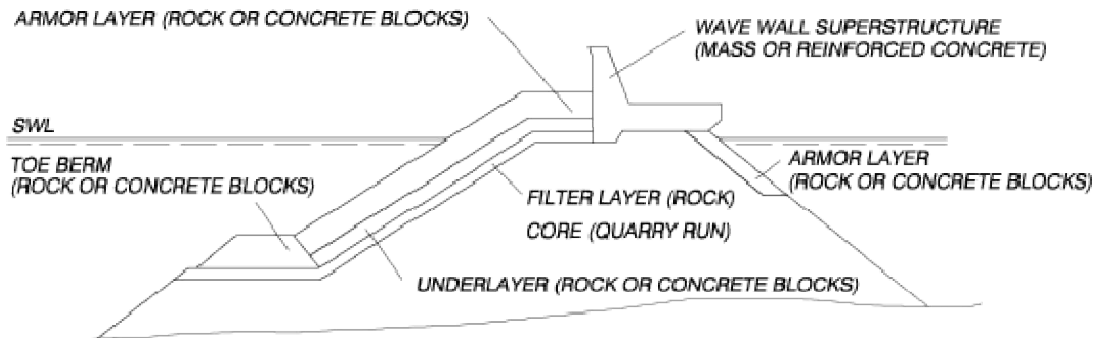
Figure 19: Multi-Layer Rubble Mound Breakwater with Superstructure [31]
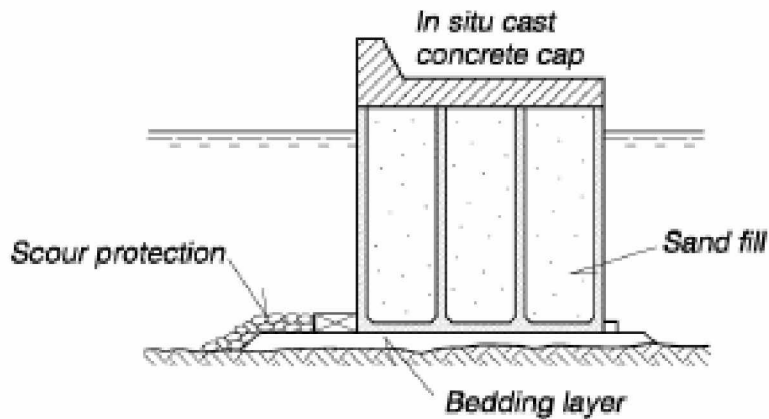
Figure 20: Conventional Caisson Breakwater with Vertical Front [31]

2.2.1.   Armour Units

"Until World War II breakwater armouring was typically either made of rock or of parallel-epipedic concrete units (cubes)". [27] Armour units are typically either randomly or uniformly placed in single or double layers. The governing stability factors are the units own weight and their interlocking ability. Breakwaters were mostly designed with gentle slopes and relatively large armour units that were mainly stabilized by their own weight. A large variety of concrete armour units has been

developed in the period of 1950-1970. Table 5 illustrates the most common armour units' development origin and periods. [27]

Table 5: Development of Breakwater Armour Units (Bakker, 2003)

Armour Unit	Country	Year	Armour Unit	Country	Year
Cube			Seabee	Australia	1978
Tetrapod	France	1950	Shed	UK	1982
Tribar	USA	1958	Accropode	France	1980
Modified Cube	USA	1959	Haro	Belogium	1984
Stabit	UK	1961	Hollow Cube	Germany	1991
Akmon	NL	1962	Core-Loc	USA	1996
Tripod	NL	1962	A-Jack	USA	1998
Cob	UK	1969	Diahitis	Ireland	1998
Dolos	RSA	1963	Samoa Block	USA	2002
Antifer Cube	France	1973			

"The failure of the Sines breakwater (Portugal, 1978) and the introduction of the Accropode by Sorgreah in 1980 set an end to the rapid development of randomly placed concrete armour units. Since then single layer randomly placed armour units have been applied." [27]

2.2.2. Armour Design

Concrete Armour units can be divided into the following categories according to structural strength: [31]

- *Massive or blocky* (e.g. cubes incl. grooved types, parallelepiped block)

- *Bulky* (e.g. Accropode®, Core Loc®, Haro®, Seabee)

- *Slender* (e.g. Tetrapod, Dolos)

- *Multi-hole cubes* (e.g. Shed, Cob)

Figure 21 illustrates the different shapes for concrete armour units
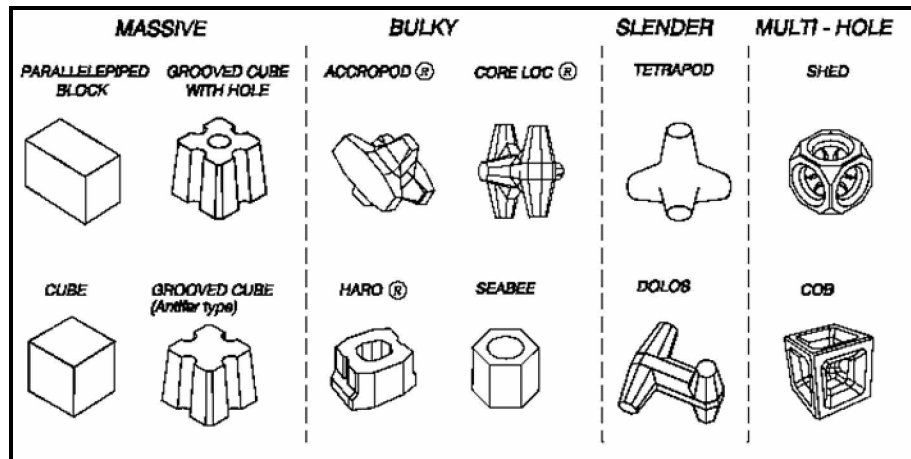
Figure 21: Concrete Armour Units Categorization and Shapes [31]

Table 6 illustrates the difference in amounts of total concrete mass using various armour unit shapes for the same wave height design (case of Port St. Francis - South Africa). It is noted that usage of cubical shaped armour units resulted in utilizing a concrete mass 136% more than using core-loc armour units.

Table 6: Comparison of Armour Units for the same Design Parameters, Case Port St. Francis [40]

Unit	Mass (t)	Total Concrete Mass (t)	Total Concrete Mass (%)	Design Wave height (m)	3-D Image
Core-loc	15.0	12 000	100 %	8.7	
Accropod	17.4	13 700	114 %	8.7	
Dolos	15.0	17 800	148 %	8.7	
Tetrapod	21.7	25 200	210 %	8.7	
Cube	21.7	28 400	236 %	8.7	

There are a number of considerations that should be taken while designing a coastal structure. According to H.F. Burcharth [31], the following are the main factors:

1. Performance of structure given by the objective

2. Determination of design loads

3. Failure modes

4. Construction procedure

5. Maintenance

6. Reliability and cost

2.2.3. Recent Developments

HDPE is used in manufacturing of breakwater structures especially floating breakwaters [90]. Such technological advancement has been utilized by Wave Dispersion Technologies, Inc. (WDT) which developed the WhisprWave® floating articulated breakwater erosion/wave and wake control system to afford protection to marinas, beaches, and private property subject to destructive or annoying wave/wake forces. The base building block of the WhisprWave® is its patented module illustrated in Figure 22. A standard module weighs approximately 36 lbs. empty, which could be filled with or evacuated of water to precisely adjust its buoyancy. The module could also be filled with marine grade buoyant foam to be "puncture proofed". WhisprWave® modules are connected using a system of Ethylene Propylene Diamine Monomer (EPDM) rubber cables, marine grade hardware and stainless steel anchoring harness. [90]

Figure 22: WhisprWave® HDPE Module[90]

Traditional breakwaters, seawalls and jetties have failed primarily because wave energy is reflected or directed in destructive ways. Sometimes wave energy forces are also concentrated in local hot spots. Erosion problems and the scouring effects of the misdirected energy lead to loss of beach / coastline. In addition, other fixed structures such as groins lead to the loss of natural flows in down-drift beaches by interrupting the littoral flows of sand and generally create a surplus condition on the up-drift side and a starvation condition on the down-drift beaches. The floating breakwaters, however, remedy the limitations of traditional breakwaters, seawalls and jetties, in their ability to be set at any depth of water, and being portable thus requiring no major construction to move it. This flexibility greatly enhances its usefulness at sites that are subject to possible changes in needs and requirements. [90]

The WhisprWave® breakwater is also superior at dissipating waves and stopping erosion problems associated with ocean wave activity. While competing products have only been observed to have transmission coefficients of up to 0.8 (dissipating 20% of the energy from waves), the WhisprWave® has been observed to have a transmission coefficient of 0.1 (dissipating 90% of the energy from waves). Hard permanent structures (rubble breakwaters) are the only competing breakwaters

that can match the WhisprWave's® durability and effectiveness. These erosion prevention structures, however, have several drawbacks, most significantly disrupting the natural ecosystem, being more expensive, and reflecting waves instead of dissipating them thus causing further erosion problems at nearby shorelines, and polluting the protected areas by impeding water circulation. [90]

Marine ecosystems require fresh water with low levels of toxic pollutants, while the floating breakwater keeps pollutant levels low by allowing water to circulate. EPA Marina Management Practices require marinas to be designed to allow for maximum flushing of the water supply for the site. Adequate flushing reduces the potential for the stagnation of water in a marina and helps to maintain the biological productivity and reduce the potential for toxic accumulation in bottom sediment. The floating breakwater benefits marine ecosystems by acting as an artificial reef, providing a safe habitat for fish, water foul, and seagulls. [90]

CHAPTER THREE
EXPERIMENTAL TESTING

This chapter presents the tests' selection criteria to evaluate the properties and serviceability of the produced sampled erosion protection structure, the production process of samples from MSW rejects, description of the machines used in producing the required samples, and finally tests procedures.

3.1. Erosion Protection Structures Testing

Prior to selecting a sample size, a review was needed to identify the type of tests for the various types of breakwater structure/armour units to ensure that the samples produced would meet the minimum qualifications according to standards for specimens sizes. The general presumption was to choose either cubical shape or rectangular shaped (massive blocks) mold for ease of production and availability of manufacturing tools on Campus; however the exact size was determined after a series of comparisons to identify the required tests for the sampled breakwater.

The types of breakwater armour units vary from being either concrete or rock; however, the material utilized in this thesis is plastic MSW rejects which was not used before as erosion protection structure or an armour unit so no standard tests were available. Accordingly the testing for properties would be selected based on judgment for significance to the material used and compilation of applicable test procedures from standard tests of various materials. Presented are the tests for rock and concrete erosion protection structures in comparison of significance to the general tests of

plastics, and finally a selection of the tests to identify the sample size. (Note that the MSW rejects as previously illustrated in chapter 1 are usually plastics/plastic bags)

3.1.1.   Rock Erosion Structures Standard Tests

Rock used for erosion control may consist of several types, depending on potential use. "One type may be armor stone weighing from one to three tons or breakwater stone weighing three to twenty tons. Another type may be riprap usually weighing less than 2 tons and placed along river banks or on the slopes of dams. A third type may be gabion-fill weighing less than 22 kg (50 lb) and placed in baskets of wire or other suitable material tied together to form an integral structure to resist erosion around bridge piers." [20] Rock for erosion control in all the different forms consists of individual pieces of natural stone, and the ability of these individual pieces to resist deterioration due to weathering action affects the stability of the integral structure for erosion control.[22] According to ASTM 4992-94 (Revised 2001), the Standard Practice for Evaluation of Rock to be used for Erosion Control, there are several tests that should be performed for the specimen to insure performance of design objectives. The tests are divided over two categories, accelerated weathering tests and physical property tests. [20]

Physical Property Tests
1.   Bulk Specific Gravity Test (ASTM D5779)

2.   Absorption Test (ASTM C127)

3.   L.A. Abrasion Test (ASTM C535)

4.   Splitting Tensile Strength Test (ASTM D3967)

5. Insoluble Residue Test (ASTM STP1177): to determine the percent of quartz, clay, or other non-carbonate minerals in a limestone or dolomite.[20]

Accelerated Weathering Tests

1. Wet-Dry Test (ASTM D5313): designed to simulate summer-time conditions of alternating rainfall and subsequent drying by the summer sun. It also simulates the rise and fall of tidal movements and water levels in reservoirs, lakes, rivers, etc. Specimens are alternately soaked in water and heated for a specified number of cycles. [23]

2. Freeze-Thaw Test (ASTM D5312): simulates the type of exposure to which the rock specimens would be subjected under winter-time conditions. Specimens are soaked in an alcohol-water solution followed by alternating cycles of freezing and thawing for a varying number of cycles. [22]

3. Sodium Sulfate/Magnesium Sulfate Soundness Test (ASTM D5240): is an indirect attempt to simulate the expansion of water on freezing. Rock specimens are subjected to alternating cycles of immersion in saturated solution of sodium or magnesium sulfate followed by oven drying to estimate qualitatively the durability of rock under weathering conditions.[21]

3.1.2. Concrete Marine Structures Standard Tests

There are no specific standards for testing of concrete used as breakwater structures. In reference to Paul Klieger and Joseph Lamond (1994) [65] a thorough evaluation is needed to be conducted in order to properly evaluate the tests mentioned in ASTM 4992 for rock and identify the need for conducting them. However, the tests for concrete include the following:

Physical Property Tests

1. Bulk Specific Gravity Test (ASTM C127, C128)

2. Absorption Test (ASTM C127)

3. Splitting Tensile Strength Test (ASTM C496)

Accelerated Weathering Tests

1. Freeze-Thaw Test (ASTM C666): is a combination of two procedures where specimen freezes in air or in water. Freeze-Thaw tests were mainly devised on "a pragmatic rather than a theoretical basis. It was assumed that the destruction resulted from the 9% volume expansion of water to ice."[65] The main concern is the concrete paste and the reaction to freezing conditions.[13]

2. Sodium Sulfate/Magnesium Sulfate Soundness Test (ASTM C88): is an indirect attempt to simulate the expansion of water on freezing and the impact on the aggregates and the concrete. Aggregate (fine/coarse) specimens are subjected to alternating cycles of immersion in saturated solutions of sodium or magnesium sulfate followed by oven drying to precipitate the salt impermeable pore spaces. "Magnesium Sulfate is more destructive than Sodium Sulfate." [65]

3. Abrasion Test (ASTM C1138): covers a procedure for determining the relative resistance of concrete (including concrete overlays and impregnated concrete) to abrasion under water. This test simulates the abrasive action of waterborne particles (silt, sand, gravel, and other solids).[15]

3.1.3. Plastics Standard Tests

Mechanical/Physical Property Tests

1. Bulk Specific Gravity Test (ASTM D792)

2. Absorption Test (ASTM D570)

3. Compression Test (ASTM D695)

Accelerated Weathering/Chemical Tests

1. UV Test (ASTM G53): to simulate deterioration caused by sunlight and dew by means of artificial ultraviolet light and condensation apparatus.[80] The test aims at testing plastic pipes for cracking, color loss, fading, chalking, crazing, hazing, blistering, gloss loss, strength loss, color change, embrittlement, and oxidation due to exposure to solar light.

2. Environmental Stress-Cracking Test of Ethylene Plastic (ASTM D1693): is designated to test ethylene plastic (especially used for extruded products as wires and pipes).[16]

3.1.4. Physical Modeling

Hydraulic physical model tests are usually done for armour units using multi-directional wave basin (Jo Vinje wave basin) to determine the hydraulic stability factor. The test setup differs from single layer arrangement to double or random arrangement. [45]

Another test is the Wave run-up test, where measured prototype storms are simulated and parametric tests are performed. Wave run-up is accurately detected by a

novel step gauge. The wave run-up is taken into account in the design of the crest level of sloping coastal structures. [42]

3.1.5. Tests Selection

Accordingly, the selection of the series of tests to be conducted on the sampled erosion protection structure would be as follows:

Mechanical/Physical Property Tests

1. Bulk Specific Gravity Test (ASTM D792)

2. Absorption Test (ASTM D570)

3. Compression Test (ASTM D695)

4. Abrasion Test (ASTM C1138)

Accelerated Weathering/Chemical Tests

5. Wet-Dry Test (ASTM D5313)

6. Sodium Sulfate/Magnesium Sulfate Soundness Test (ASTM D5240)

Environmental Tests

7. Analysis of leachate from immersion in fresh and sea water.

8. Stack emission analysis from mixing furnace.

The tests that were ruled out in the rock/concrete tests are the physical property tests due to their irrelevant to the material used, especially that standard physical property tests for plastics exist. The mechanical tensile strength test was changed to use the compression test instead because it is more appropriate for the intended use where wave actions cause compressive loading on one side of the

armour unit. In addition to the fact that material faults (voids) are compressed during the test procedures thus properly identifying strength and stiffness.

As for the accelerated weathering tests, freeze-thaw was ruled out due to the fact that it tests the concrete paste and voids in rock assembly whereas in our sampled product sand is only used as a filler material so no expected behavior as mentioned in the standards is expected. In addition to the fact that sulfate soundness test is an "optional substitute test for freezing and thawing test" [14]. The accelerated weather tests for plastics are irrelevant due to its focus on pipes and wires which are different forms of the intended function and shape of the sampled material.

This work is not intended to introduce a new armour unit but utilizing an existing shape so physical/hydraulic tests for stability coefficients and drop tests are not investigated in this work scope.

3.2. Sample Production

The nominal sizes of wave protection concrete structures (non-floating breakwater) cubical armour unit 2 and 20 tons are illustrated below:

Table 7: Cube Armour Unit Dimension Calculations

Concrete Cube Armour Unit	Density (Kg/m3)	Mass (Kg)	Volume (m3)	Side Width (m)	Width (cm)
Min 2 Tons	2400	2000	0.833333	0.941036	94.1036
Max 20 Tons	2400	20000	8.333333	2.027401	202.7401

Most of the standard tests presented earlier indicate a minimum specimen size; mostly the sample shouldn't be less than 125 mm on side and 65 ±5mm thick. The selection for this thesis procedure was to manufacture a sample unit on a 1:10 scale, so a square sample was selected to be of width of 125 mm and 65 ±5mm thick.

Standard tests indicated a minimum number of 3 samples for physical/mechanical property tests and 5 samples for rock weather tests. However, the rock tests needed more number of samples due to the multiplicity of rock lithological structure. So for the sake of unifying the tests, a number of three samples per mix were used in each test.

In reference to tests conduced earlier on the same material in another thesis work [1], the results showed good properties at a sand mix ratio of 40%, but samples produced contained sand mixes with increments of 20% below and above the 40%. In guidance to the results illustrated in this later work, the selection was to use different mixing ratio increments of 10%, so the mixing would be at 30, 40, and 50% respectively with comparison to a zero percent mix. The sand sieve used is 2.36 mm (sieve 8). Two sets of samples were produced according to Table 8.

Table 8: Sample Set Production

MIX #	First Sample Set			Second Sample Set		
	Sample #	*Sand %*	*Temp (°C)*	*Sample #*	*Sand %*	*Temp (°C)*
Mix 0	1	0	140			
	2	0	140			
Mix 1	3	30	140	18	30	140
	4	30	140	19	30	140
	5	30	140	20	30	140
	6	30	140			
Mix 2	7	40	140	21	40	140
	8	40	140	22	40	140
	9	40	140	23	40	140
Mix 3	10	50	140	24	50	140
	11	50	140	25	50	140
	12	50	140	26	50	140
Mix 4	13	40	160	27	40	160
	14	40	160			
Mix 5	15	40	180	28	40	180
	16	40	180			
Mix 6	17	30 +25% H2O	160			

As mentioned earlier in this section, 3 samples are needed per test at each mix ratio, so a total number of 9 samples per test. However, as the physical/mechanical property tests are non-destructive tests, so the same samples were used in the absorption, specific gravity and finally compression test respectively. Accordingly, a second set was produced for the weathering tests of wet-dry and soundness. As for the abrasion and environmental analysis tests, samples were needed to be produced from real waste rejects, a number of 5 samples were produced in the APE. (Shown below)

Figure 23: Sample from MSW Rejects produced at APE

3.3. Process Description

The main material used in physical/mechanical and accelerated weathering tests are solid waste plastic bags (LDPE). The bags are agglomerated to produce fine laminates as shown in Figure 24. The agglomerated material is then mixed with filler material sand in different ratios (Figure 25). The mix is then indirectly heated in a furnace at different temperatures to produce a paste which is pressed in a prefabricated mold to the dimensions predetermined in the previous section. The product is then machined to cut off the excess paste to produce shoreline erosion protection unit (Figure 26). A process flowchart is presented in Figure 27.

Figure 24: Agglomerated Plastic Bags

Figure 25: Sand, Balance and Mixed Material

Figure 26: Mix Paste *(Up Left)***; Press** *(Up Right)***; Produced Sample** *(Down)*
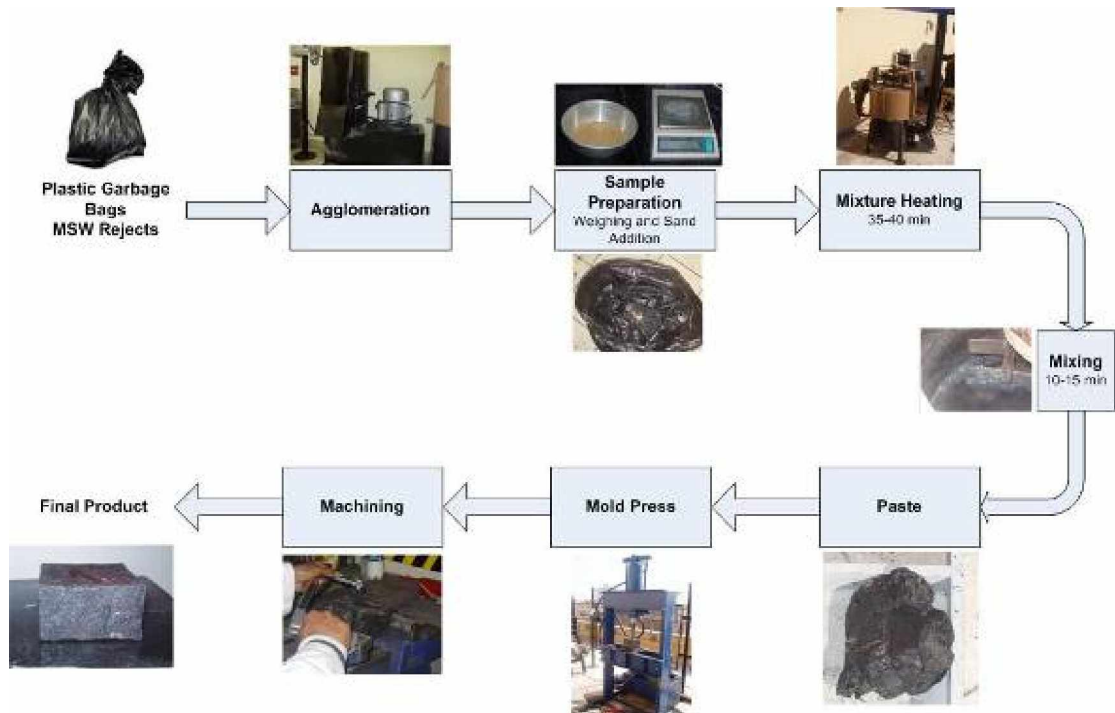
Figure 27: MSW Rejects Product Manufacturing Process Flow Chart

3.3.1. Agglomeration m/c

3.3.1.1. Specification

The agglomeration machine is based on a 980 x 410 mm steel chassis. The machine consists of a cylinder with 4 stationary knives and 4 rotating ones as shown in Figure 28. The cylinder is 410 mm in diameter. The motor used to operate the machine is 10 Hp @ 1450 rpm (3 Phase). Two pulleys are used to transmit the motor power to the rotating disc (320 mm in diameter). The schematics for the machine are shown in Figure 29.

3.3.1.2. Operation

Plastic is fed to the machine through the upper lid. The rotary disc containing 4 knives rotate via the power transmitted from the motor. The four stationary knives on the cylinder are about 30 mm higher than the rotary disc and are used in association with the rotating knives to shred the plastics into small pieces. A door is used near the bottom of the machine for the release of the product.

Rotating Knives

Stationary Knives
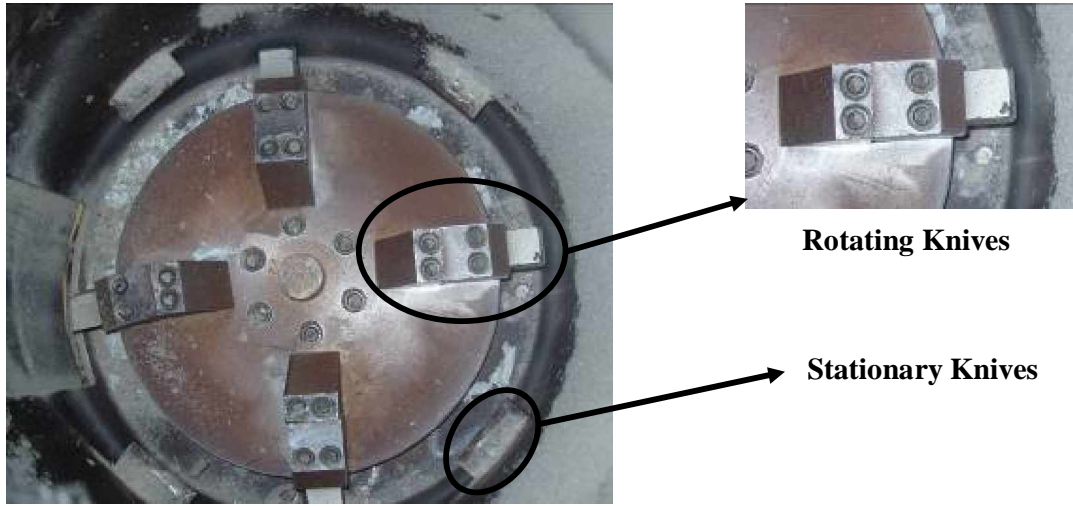
Figure 28: Agglomeration Machine
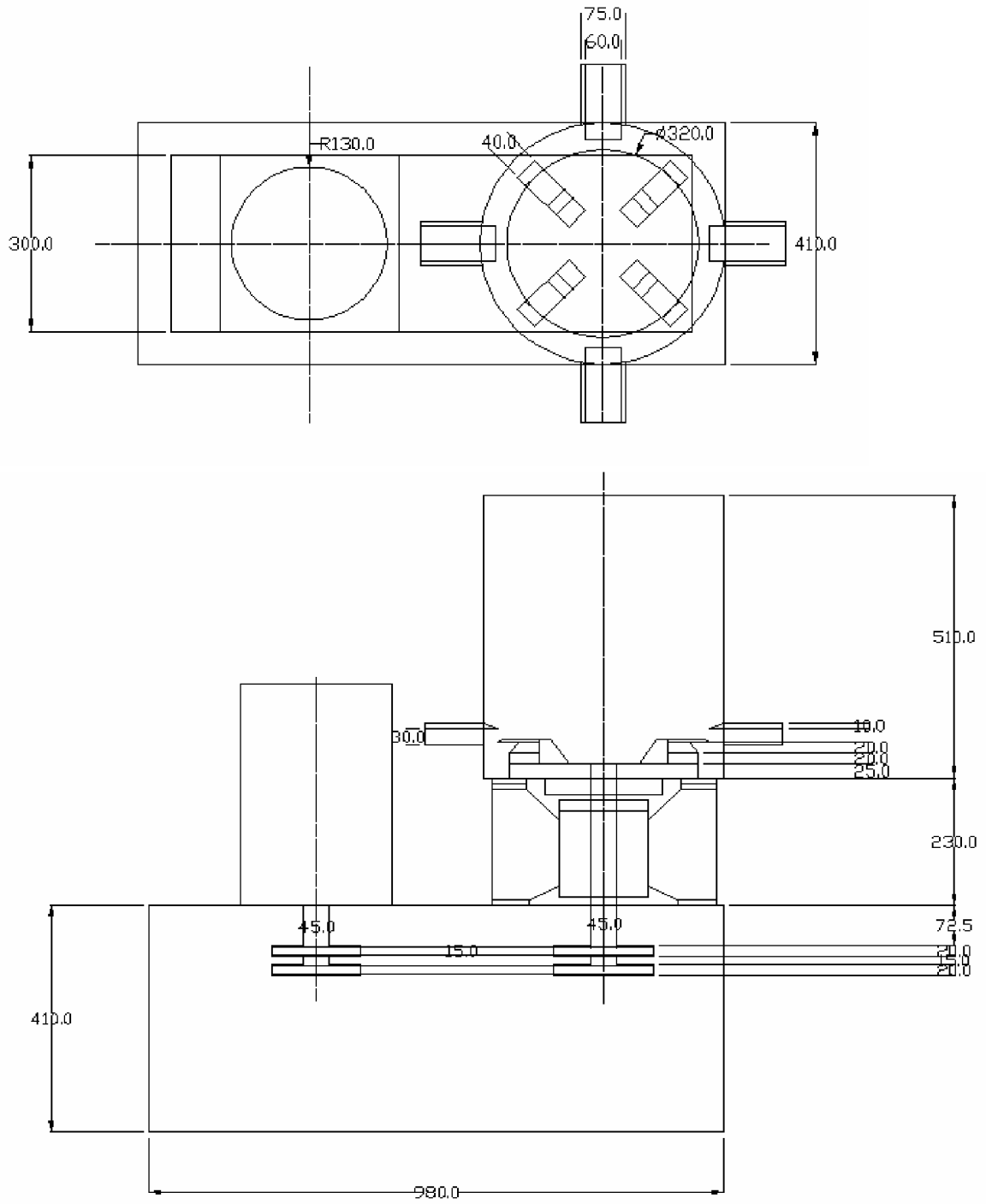
Figure 29: Agglomeration Machine

3.3.2. Furnace

3.3.2.1. Specification

The furnace consists of a 650 mm diameter cylinder 350 mm in height. It is equipped with a one horsepower motor controlled via gear box that transmits its power output to a three gear system fixed at the top of the cylinder as shown in Figure 31 & Figure 30. The fuel used to heat the mix is butane gas. A 1/3 Hp blower is attached to the side of the furnace to collect gases from mixing chamber and into the combustion chamber. The temperature inside the chamber is controlled through a thermostat and a control unit. When mixing action is required, the motor operates and the gears rotate two 44 mm diameter shafts fitted with blades to stir the mixture.

3.3.2.2. Operation

The plastic from the agglomeration machine is mixed with sand and fed through the upper lid into the furnace. The machine operates for about 30-40 minutes in order to reach a temperature of about 140°C. The stirring action starts when temperature reaches 90°C. When the mixture is melted, the motor is then started to operate the gears rotating the two blades inside the cylinder to stir the mixture. The mixture is stirred for about 10-15 min, and then the sliding plate (door) at the bottom is removed to drop the paste to be pressed using the hydraulic press shown in Figure 32. The blower collects the gases from the mixing chamber and uses it as a secondary fuel to the combustion chamber.
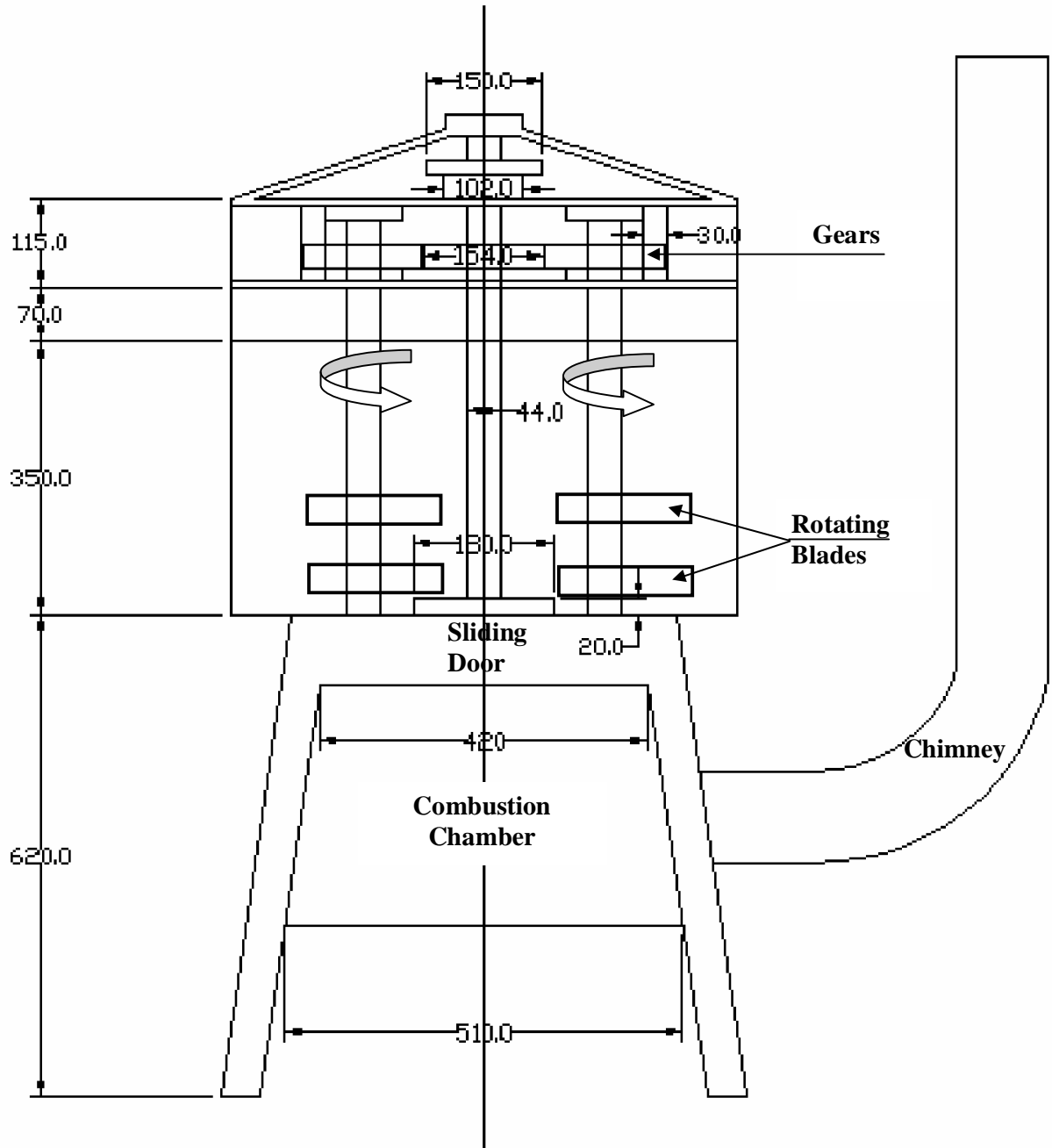
Figure 30: Furnace

Figure 31: Furnace

Figure 32: Mold and Press Machine

3.4. Test Procedures

3.4.1. Absorption Test [(17)]

Absorption is an indicator of the amount of moisture absorbed. The moisture content of plastic is related to such properties as electrical insulation resistance, dielectric losses, mechanical strength, appearance, and dimensions. Change in moisture content affects these properties. Rate of water absorption depends largely on the type of exposure (immersion in water or exposure to high humidity), shape of the part, and inherent properties of the plastic.

According to standards, specimens of materials whose water-absorption value would be appreciably affected by temperatures in the neighborhood of 110°C (230°F), should be dried in an oven for 24 h at 50 ±3°C (122 ±5.4°F), cooled and immediately weighed to the nearest 0.01 g. The conditioned specimens are then placed in a container of distilled water maintained at a temperature of 23 ±1°C (73.4 ±1.8°F). The

samples (set 1) were entirely immersed. At the end of 24h +1⁄2h −0h, the specimens were removed from the water one at a time, all surface water wiped off with a dry cloth, and weighed to the nearest 0.01 g immediately (Figure 33 illustrates the test procedures). The calculation for the absorption percent is according to the following equations.

$$\text{Absorption \%} = \frac{(Wt_{wet} - Wt_{conditioned})}{Wt_{conditioned}} \times 100 \tag{1}$$

Figure 33: Conditioning (*Up Left*), Weighing (*Up Right*) and Immersion (*Center*)

3.4.2. Specific Gravity Test [18]

Specific gravity (relative density) is the ratio of the mass in air of a unit volume of the impermeable portion of the material at 23°C to the mass in air of equal density of an equal volume of gas-free distilled water at the same temperature. Density is the mass in air in kilograms per cubic meter of impermeable portion of the material at 23°C.

The specimens (set 1) are conditioned at 23 ±2°C and 50 ±5 % relative humidity for 40 h. The water temperature was measured, and the specimens were weighed in air to the nearest 0.01 g. A special weight apparatus is set where the sample is being hung in a bucket in water which is hooked to a balance. The balance is reset to only calculate the weight of sample in water. Figure 34 shows the weighing apparatus. The specific gravity and density are calculated as per the equations below:

$$Specific\ gravity = \frac{Wt_{conditioned}}{(Wt_{conditioned} - Wt_{immersed})} \times 100 \qquad (2)$$

$$Density = Sp\ Gr\ x\ 997.5 \qquad (3)$$

Figure 34: Weighing Bucket

3.4.3. Compression Test [19]

Compression tests provide information about the compressive properties of plastics such as modulus of elasticity, yield stress, and compressive strength.

The specimens (set 1) were conditioned at 23 ±2°C and 50 ±5 % relative humidity for 40 h in accordance to the test method ASTM D695. The 810 MTS testing machine with a load cell of 500 KN was used, and the machine was set at a compression rate of 1.3 mm/min. The dimensions of all specimens were measured. The specimens were loaded on two planes (perpendicular and parallel to the loading face). Figure 35 shows the different machines used in this experimental procedure.

Figure 35: MTS Machine (*Left*), Parallel Loading (*Center Up*), Perpendicular Loading (*Center Down*), Fracture Machine (*Right*)

3.4.4. Wet-Dry Test [(23)]

As mentioned earlier in this chapter, this accelerated weathering test is designed to simulate summer-time conditions. The procedure as specified in Test Method D5313 is stated for rock, so the preconditioning temperature was altered to suit the plastic material. The specimens (set 2) were conditioned at 23 ±2°C and 50 ±5% relative humidity for 40 h and then weighed. Specimens were placed in a container with enough potable water such that the specimens are fully immersed and were let stand for a minimum of 12 h. The samples were then dried in an oven at a temperature of 60 to 70°C (140 to 160°F) for a minimum of 6 h. The cycle was repeated 5 times. To determine the percent loss, the following equation is applied:

$$Percent\ loss\ \% = \frac{(Wt_{prior} - Wt_{post})}{Wt_{prior}} \times 100 \qquad (4)$$
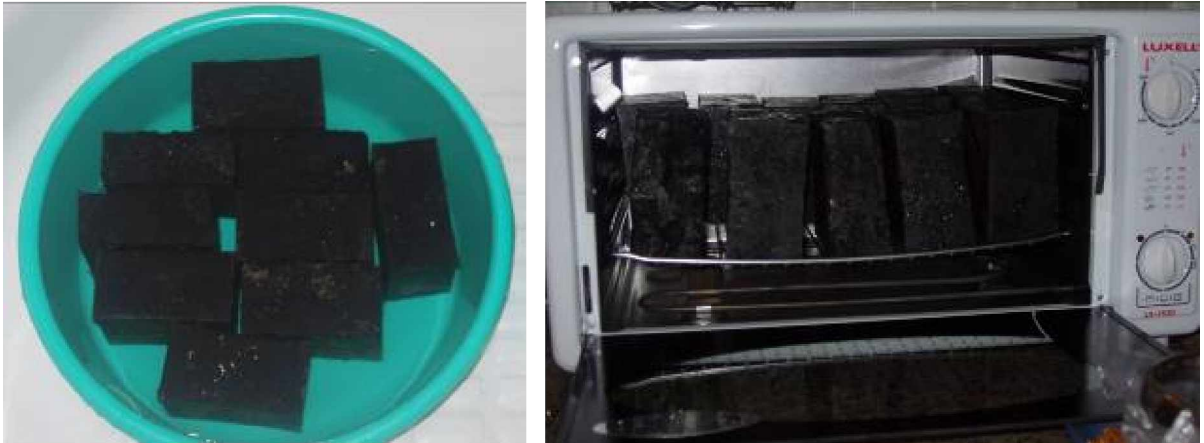
Figure 36: Wet (*Left*) – Dry (*Right*) Test

3.4.5. Soundness Test [21]

The soundness test is also designated for rock, but it was used as a guideline to devise this method for plastic rejects testing. However, the solution was prepared in accordance to the standard. Magnesium Sulfate was selected because it's more destructive than Sodium Sulfate [65].

A saturated solution is prepared by dissolving equal grade of the salt in water at a temperature of 25 to 30°C (77 to 86°F). 350 g of crystalline $MgSO_4$ salt are mixed per 1 liter of water and 1240 gm of $MgSO_4$ heptahydrate solution per liter of water [8]. A solution mixture was prepared using 7 Kg of $MgSO_4$ Heptahydrate and 500 gm of crystalline salt were added to a total of 7 liters of water. The mixture is being stirred at frequent intervals during the addition of the salt. The solution was covered at all times to reduce evaporation and prevent contamination. The solution is then allowed to cool to 21 ±1°C (70 ±2°F), and again stirred, and then allowed to remain at the designated temperature for 48 h before use.

Barium Chloride Solution is prepared by dissolving 5 g of $BaCl_2$ in 100 mL of distilled water.

The specimens (set 2) were conditioned at 23 ±2°C and 50 ±5 % relative humidity for 40 h and then weighed. Specimens were immersed in the sulfate solution for not less than 16 h nor more than 18 h in such a manner that the solution covers them to a depth of at least 1.27 cm (1⁄2 in); however, the samples floated due to the increased salt concentration. The container was covered to reduce evaporation and prevent the accidental addition of extraneous substances. The samples were supposed

to be immersed and maintained at a temperature of 21 ±1°C (70 ±2°F) for the immersion period. Specimens were then removed and left to drain for about 15 ±5 min, and placed in an oven. The samples are dried in an oven to a constant mass at 60 ±10°C at intervals of 2-4 h. The process of immersion and drying is repeated for a total of five cycles. The specimens are then washed with barium chloride and hot water (43±6°C) and weighed. Calculation of the % soundness loss is in accordance to the following equation:

$$\% \ Soundness \ Loss = \frac{(Wt_{prior} - Wt_{post})}{Wt_{prior}} \times 100 \qquad (5)$$

Figure 37: MgSO4 Solutions *(Up Left)*, **Samples Immersed** *(Up Right)*; **Samples in Oven** *(Bottom)*

3.4.6. Abrasion Test [15]

This test covers a procedure for determining the relative resistance of concrete to abrasion under water. The test method was used as a guideline to be used to simulate abrasion under water on the sampled plastic material. The specimen is placed in an agitation rotating device (washing machine) where 25 chrome steel grinding balls of diameter 15 mm are being laid down on the surface for the abrasion action. The standard test specifies a 1200 rpm rotating device to be operated for six 12h periods. The machine was found to operate at 610 rpm, so a motor operating at 1500 rpm was fitted with agitating blades and attached to the assembly (Figure 38). The 12 hour period could not be achieved due to the University constraints, so the machine was left to operate for 24 hour period, and then specimens weighed at the time and replaced again till completion of the six 12 h period that is three 24 h period. The calculation of abrasion loss is as follows:

$$Vt = \frac{(W_{air} - W_{water})}{G_w} \qquad (6)$$

Where:

Vt = Volume of specimen at desired time, m3
W_{air} = Mass of specimen in air, Kg
W_{water} = Mass of specimen in water, Kg
G_w = unit weight of water, Kg/m3 (997 Kg/m3)

To calculate volume lost at the end of any time increment:

$$VLt = Vi - Vt \qquad (7)$$

Where:

VLt = Volume of specimen lost by abrasion at end of time, m3
Vi = Volume of specimen before testing, m3
Vt = Volume of specimen at end of testing, m3

To calculate average depth of wear:

$$ADAt = VLt/A \hspace{4cm} (8)$$

Where:

ADAt = Average depth of abrasion at end of test, m
VLt   = Volume of specimen lost by abrasion at end of time, m3
A   = Area of top specimen, m2

Figure 38: Abrasion Modified Washing Machine, Samples and Chrome balls

3.4.7.   Leachate Test

Two specimens from plastic rejects were immersed; one in sea water and the other in tap (fresh) water for a period of 28 days. Water is then analyzed in accordance to DIN 38414-S4. The following parameters were analyzed:

§ pH
§ Total Dissolved Solids (TDS)
§ Total Suspended Solids (TSS)
§ Chemical Oxygen Demand (COD)
§ Nitrates & Nitrites
§ Heavy metals (Chromium, Cadmium, Lead)

3.4.8. Emission Test

During manufacturing of the samples in the furnace, exhaust is emitted to the atmosphere. Exhaust emission test was conducted using a portable device Testo 350 Flue Gas Analyzer (Figure 39) for ensuring air quality confirmation to the standards.

Figure 39: Flue Gas Analyzer and Exhaust Testing

CHAPTER FOUR
RESULTS & DISCUSSION

"The primary considerations in the selection of a material for use in a coastal structure are availability, strength, durability, material life as compared to the desired life of the structure, costs, ease of maintenance, and maintenance costs." [91] Considerations for material selection are based on the following structural properties:

1. Specific gravity: high specific gravity material for submerged structure

2. Material strength

3. Resistance to cyclic and impact loading: to consider the material flexibility within the elastic limit

4. Resistance to seismic forces

5. Material flexibility

6. Structural size

Presented hereafter are the results of the pre-selected tests to properly evaluate the serviceability and suitability of MSW plastic rejects as erosion protection structures.

4.1. Mechanical Properties

4.1.1. Absorption

The test was conducted on 24 h basis of immersion for samples of set 1; Table 9 presents the data of absorption percent while the mix averages are presented in Table 10.

Table 9: Data for Absorption Test

MIX #	Sample #	Sand %	Temp °C	Weight cond. (gm)	Weight Wet (gm)	% Absorption
Mix 0	1	0	140	771.4	772.12	0.09337
	2	0	140	924.54	926.02	0.16008
Mix 1	3	30	140	1064.86	1069.64	0.4489
	4	30	140	1086.03	1089.21	0.2928
	5	30	140	1082.45	1085.68	0.2984
	6	30	140	774.51	778.4	0.5023
Mix 2	7	40	140	1118.03	1123.74	0.5107
	8	40	140	1482.01	1487.07	0.3414
	9	40	140	1155	1160.42	0.4693
Mix 3	10	50	140	1249.97	1259.94	0.7976
	11	50	140	1353.55	1360.27	0.4965
	12	50	140	1356.25	1362.23	0.4409
Mix 4	13	40	160	1386.46	1390.24	0.2726
	14	40	160	1003.56	1005.85	0.22818
Mix 5	15	40	180	1115.63	1119.95	0.3872
	16	40	180	1040.8	1041.86	0.101845
Mix 6	17	30% + 25%H2O	160	1213.85	1215.84	0.1639

Table 10: Absorption % Averages for Different Mixes

MIX	Sand %	Temp	% Absorption
0	0	140	0.1267
1	30	140	0.386
2	40	140	0.440
3	50	140	0.578
4	40	160	0.2504
5	40	180	0.2445
6	30% + 25% H2O	160	0.1639

It is noted that there exist a variation within mix 1 for samples 3&6 to samples 4&5, and this could be due to the irregular uncontrolled distribution of sand content within the samples. A similar manner was found between sample 10 and samples 11&12. So it should be noted that sand used as a filler material could cluster and thus increasing the area of plain plastic material (without filler) leading to an increased rate of absorption.

The absorption was noticed to increase with the increase of sand content that could be due to the increase in porosity of sand allowing for more absorption. However, the increase in temperature for the same sand content (40%) did decrease the rate of absorption, and this could be due to the fact that the plastic particles melt more and are thus more homogenously connected lowering the interspatial spaces and allowing for less absorption rates. The addition of water to the 30% sand content did decrease the absorption rate and this could be due to more mixing of particles and filling of voids while sample preparation.

4.1.2. Specific Gravity & Density

Specific gravity and density is a measure of material occupation within a given volume. After the samples were immersed for 24 h in the absorption test, samples were conditioned and then tested as per ASTM D792. The results for specific gravity and density are given in Table 11 with averages in Table 12:

Table 11: Data for Specific Gravity Test

MIX #	Sample #	Sand %	Temp °C	Weight Dry (gm)	Weight in water (gm)	Specific gravity	Density (Kg/m3)
Mix 0	1	0	140	771.41	-12.5	0.9841	981.594
	2	0	140	924.51	-14.8	0.9842	981.783
Mix 1	4	30	140	1086.11	95.5	1.0964	1093.664
	5	30	140	1082.36	101.4	1.1034	1100.610
	6	30	140	774.54	74.7	1.1067	1103.972
Mix 2	7	40	140	1118.16	125.4	1.1263	1123.499
	8	40	140	1482.1	191.5	1.1484	1145.510
	9	40	140	1155.2	145.9	1.1446	1141.694
Mix 3	10	50	140	1250.01	179.7	1.1679	1164.976
	11	50	140	1353.81	200.6	1.1739	1171.014
	12	50	140	1356.2	220.7	1.1944	1191.378
Mix 4	13	40	160	1386.33	185.6	1.1546	1151.686
	14	40	160	1003.55	120.1	1.1359	1133.104
Mix 5	15	40	180	1115.55	131.1	1.1332	1130.338
	16	40	180	1040.76	142.5	1.1586	1155.743
Mix 6	17	30 +25% H2O	160	1213.45	103.9	1.0936	1090.907

Table 12: Specific Gravity and Density Averages for Different Mixes

Mix	Specific Gravity	Density (gm/cm3)
Mix 0	0.984	0.982
Mix 1	1.102	1.099
Mix 2	1.140	1.137
Mix 3	1.179	1.176
Mix 4	1.145	1.142
Mix 5	1.146	1.143
Mix 6	1.094	1.091

The zero percent sand content samples floated as they are less dense than water (average density of 0.982 gm/cm3 less than that of water). Apart from floatation of zero percent sand, the specific gravity was noticed to increase with the increase in sand content and slightly changed when temp changed.

In comparing the variation of specific gravity and absorption with sand content and temperature, the graphical representation in Figure 40 shows that the specific gravity increases with the increase in sand content, and that is a direct result to the presence of sand as a filler material; however, the absorption percent increased with the increase of sand content which could only reveal existence of more intermolecular spaces associated with the presence of sand allowing for more absorption. Accordingly when the temperature increased for the same sand content percentage, the absorption percent dropped as in Figure 41, while the specific gravity slightly increased.
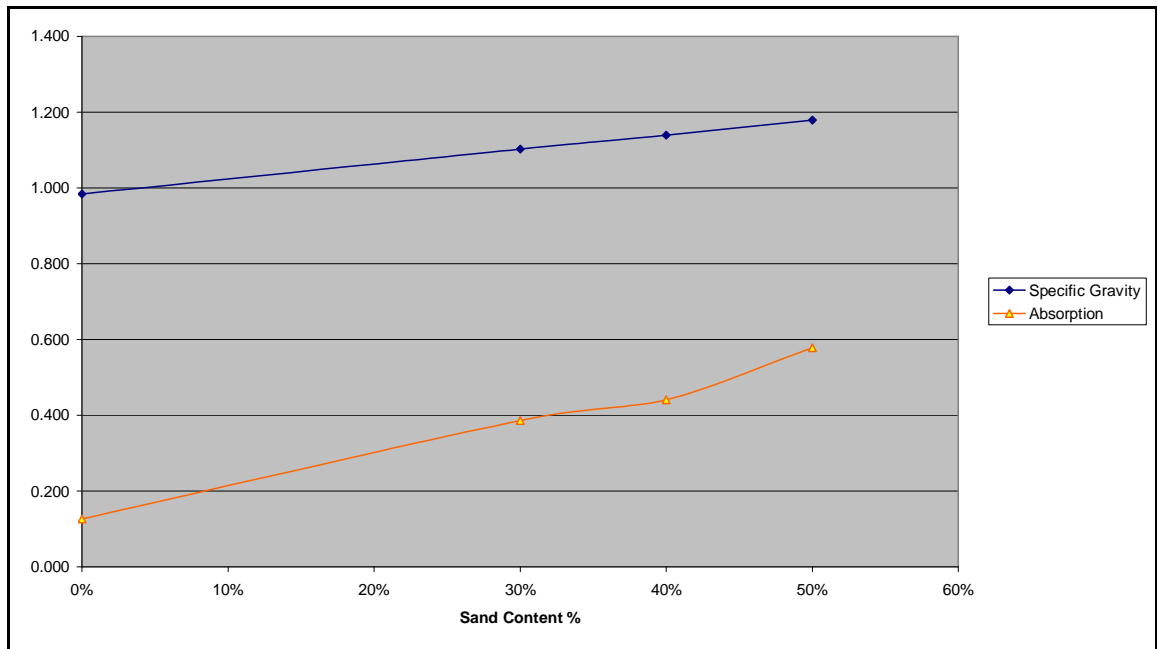
Figure 40: Specific Gravity and Absorption Properties Variation and Sand Content
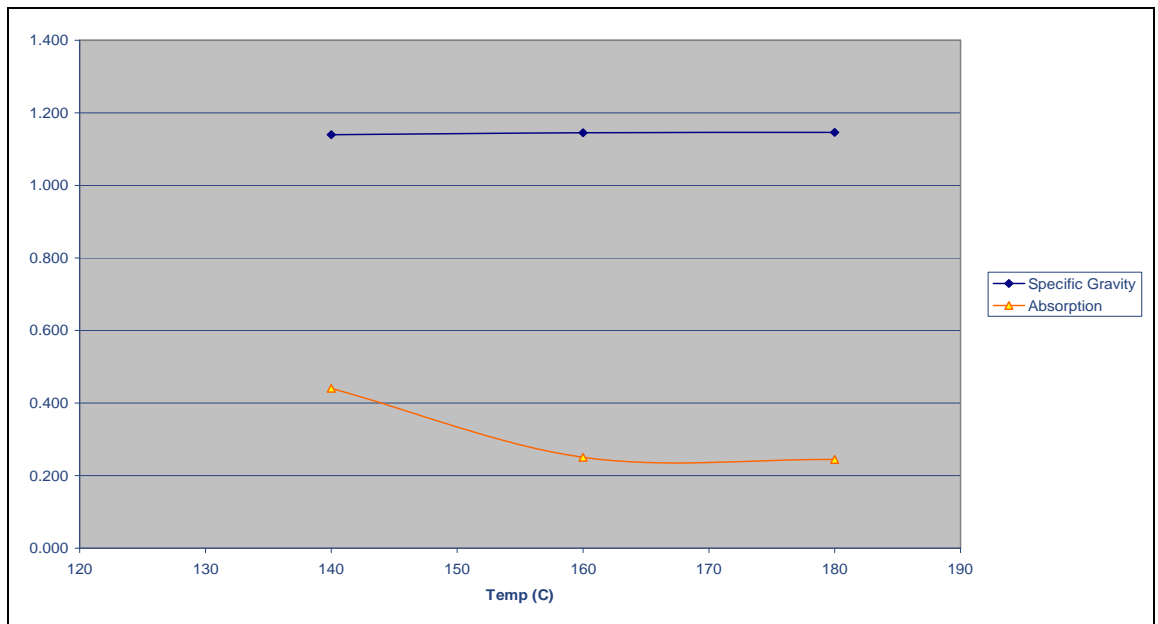
Figure 41: Specific Gravity and Absorption Properties Variation with Temperature

4.1.3.   Strength and Modulus of Elasticity

The samples were compressed on the MTS 810 machine. Samples were subjected to loading at a rate of 1.3 mm/min. The loading was applied on the two planes of the samples (parallel and perpendicular to the loading plane). Data for force and elongation are digitally measured and electronically stored, from which stress strain relationship was derived and presented in Figure 44 through Figure 47. The important properties from this experiment are the modulus of elasticity, which is a measure of stiffness, and the ultimate strength beyond which failure is initiated.

Parallel loading is performed on samples parallel to the loading plane. Since the height of the sample is more than the width of the surface thus it resulted in buckling of the samples (Figure 42). However, due to slight surface irregularities, sometimes the loading is not totally distributed over the surface resulting in slight errors in the stress strain diagram, particularly the start of the loading phase.

Figure 42: Sample under Parallel Loading

It was noticed that the samples under perpendicular loading (perpendicular to the loading surface) did not break. The maximum load of the machine is 500 KN; however, it could not be reached for operational safety purposes so the maximum load

applied on this plane was 400 - 450 KN. Loading on the perpendicular plane resulted

in compressing the specimen more and slight barreling as in Figure 43.
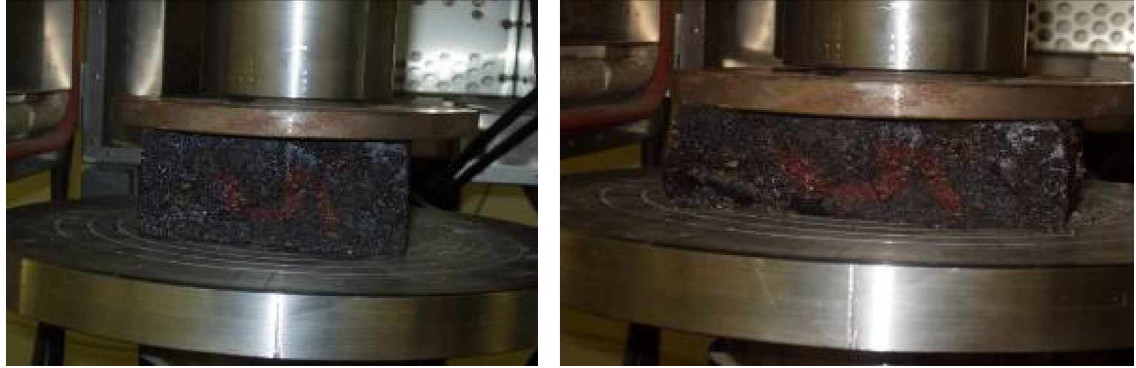
Figure 43: Perpendicular Loading *(Before and After)*
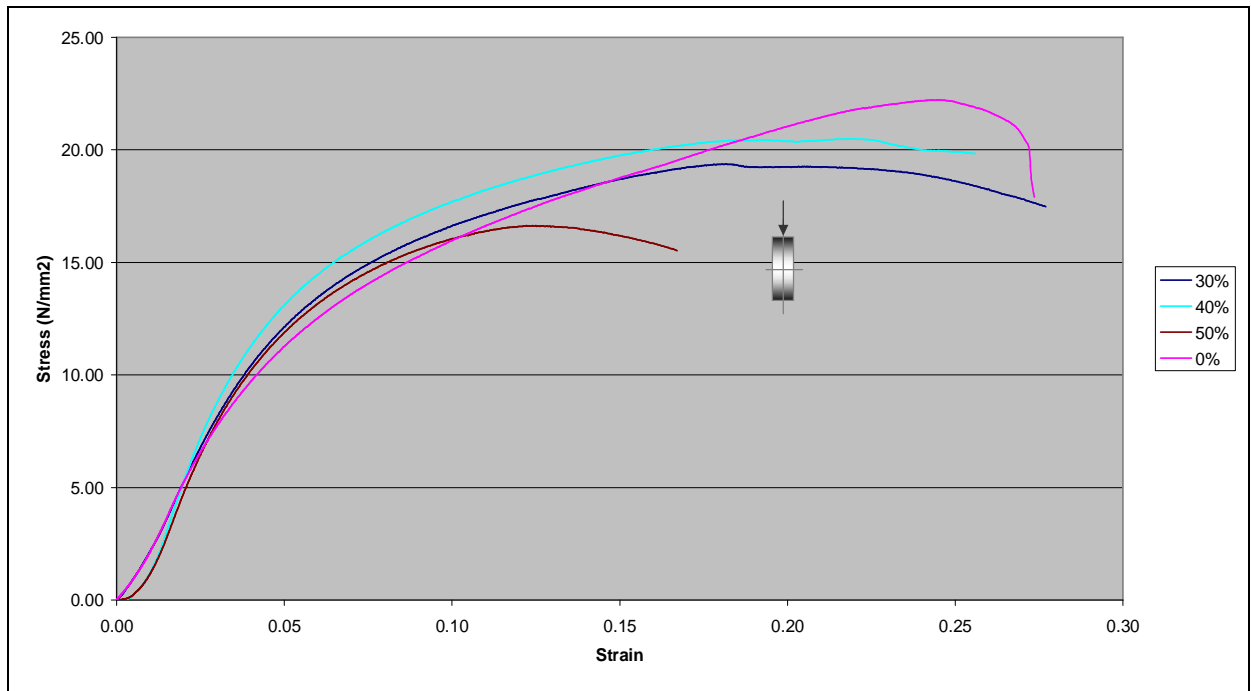
Figure 44: Stress Strain Diagram for Parallel loading variation with Sand Content
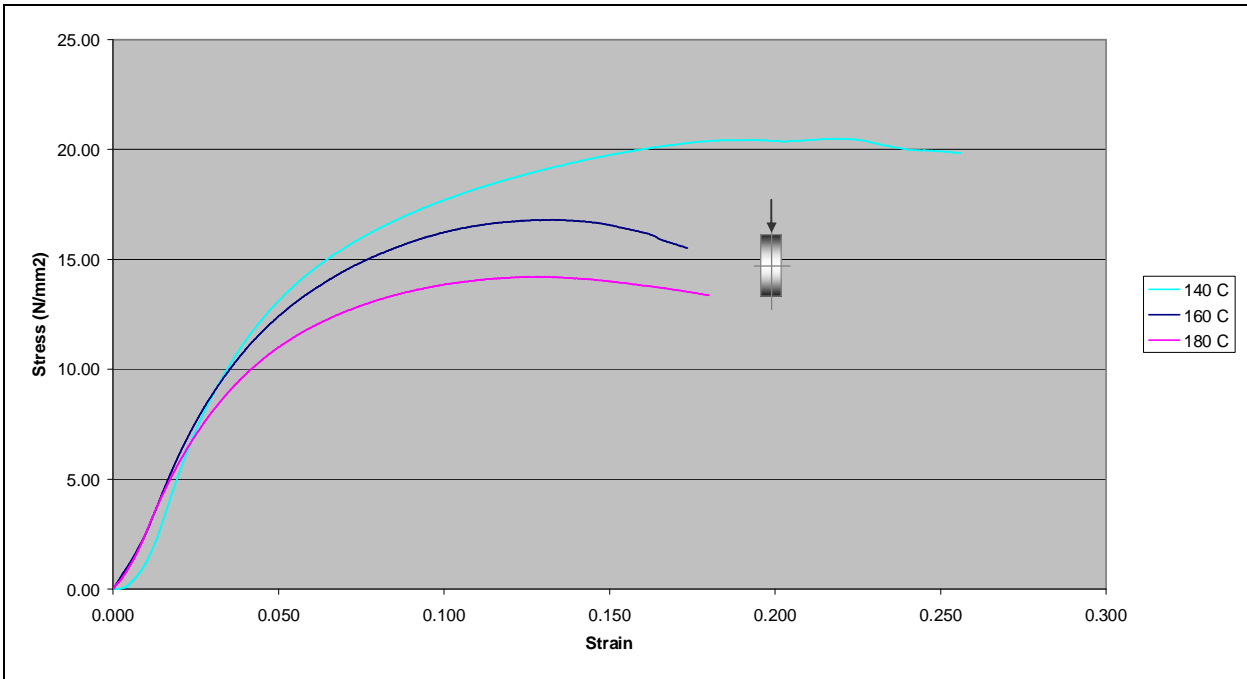
Figure 45: Stress Strain Diagram for Parallel Loading and Variation with Temperature
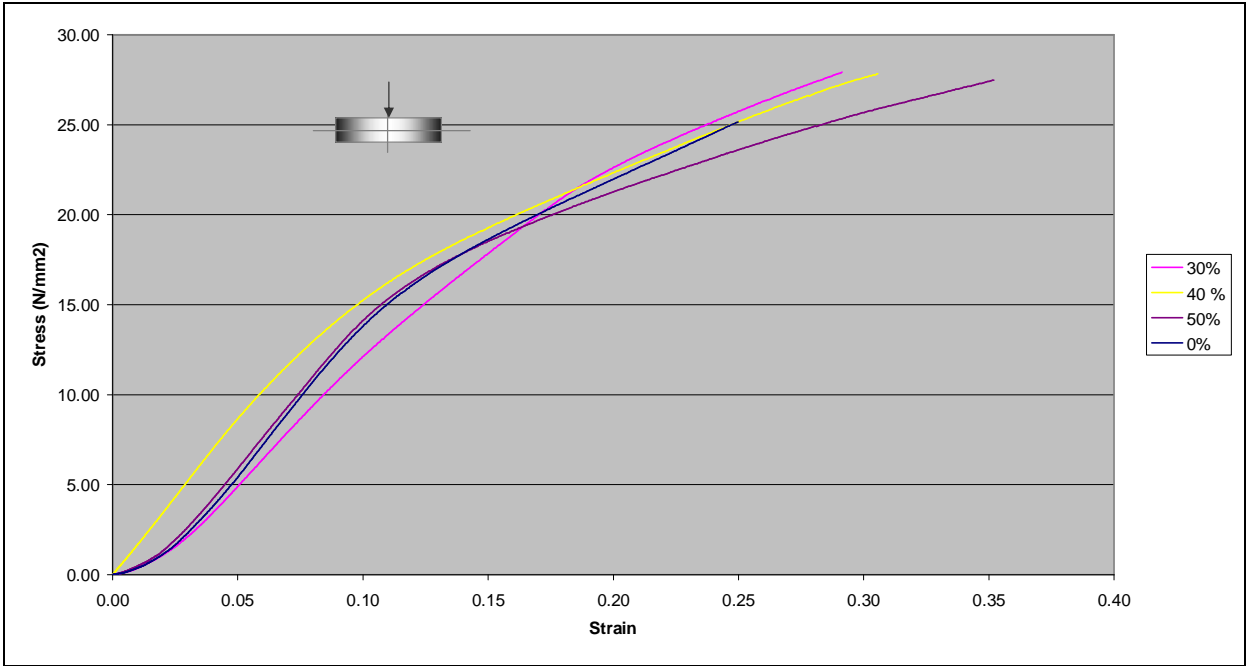
Figure 46: Stress Strain Diagram for Perpendicular Loading and Variation with Sand Content
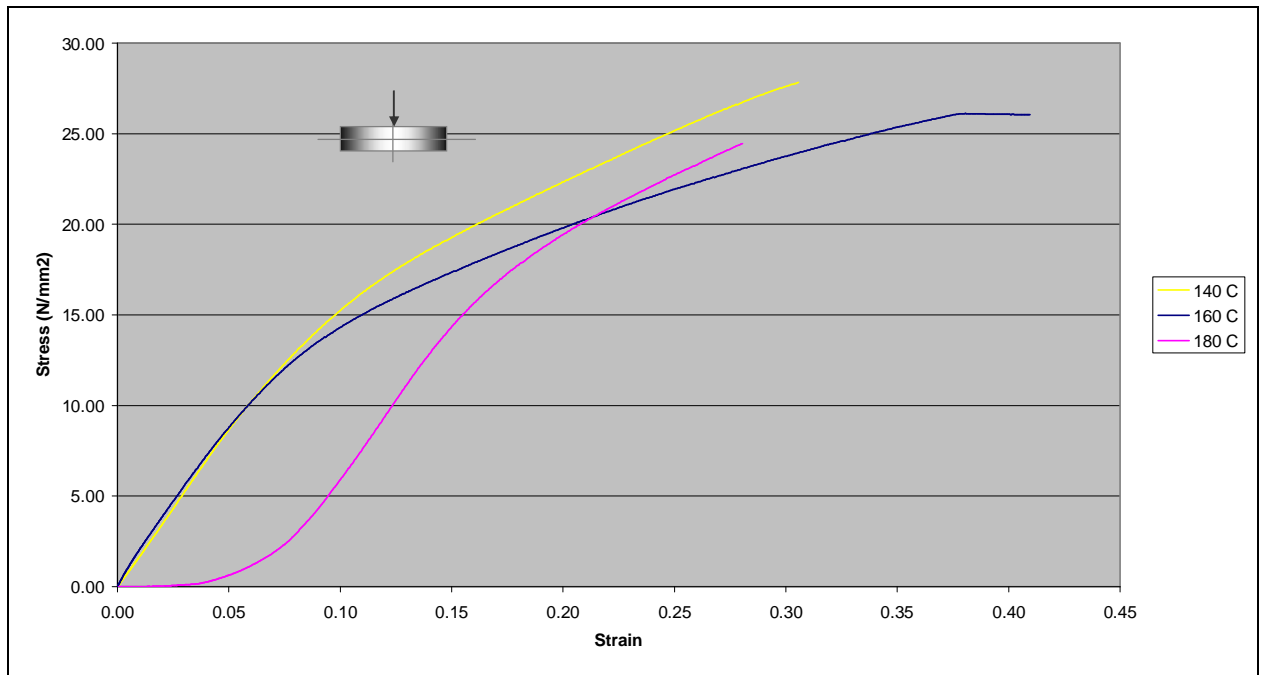
Figure 47: Stress Strain Diagram Perpendicular Loading and Variations with Temperature

When examining Figure 44 - parallel loaded samples, the zero percent sand showed a higher ultimate strength, while the 50% sand resulted in the lowest strain value. In order to properly interpret the stress-strain diagrams, the Young's Modulus (E) and the Ultimate Strength were calculated and identified for material properties comparison purposes. The following tables present the data from the stress-strain diagram (Figure 44&Figure 45).

Table 13: E and UTS with Sand Content Variation at 140ᵒC (Parallel Loading)

Sand Content	Young's Modulus (MPa)	Ultimate Strength (MPa)
0%	283.911	22.216
30%	317.876	19.369
40%	324.168	20.481
50%	345.223	16.629

Table 14: E and UTS with Temperature Variation using 40% Sand Content Samples (Parallel Loading)

Temp (^oC)	Young's Modulus (MPa)	Ultimate Strength (Mpa)
140	324.168	20.481
160	293.747	16.801
180	287.109	14.209

It is noted that the stiffness (E) increased with the increase in sand content and that argument could be due to the fact that the filler material is stiff thus adding to that of the plastic rejects. However, when comparing the temperature effect on the 40% sand content sample, the stiffness was noticed to decrease, and again this could be due to the homogenous distribution of plastic particles thus endowing more of the plastic behavior as being less stiff. On the other hand, the ultimate strength was higher in the zero percent sand, which regained partial elastic behavior. The ultimate strength was noticed to decrease with the sand content, 30 & 40% were close, while 50% decreased by 20%. Thus the more stiff material possessed lower ultimate strength. While the increase in temperature, resulted in decrease in stiffness as anticipated due to homogenous distribution and thus typical plastic behavior (could be compared to 0% sand), a non typical relation was found as the increase in temperature resulted in decrease in ultimate strength, while more homogeneity should have revealed more ultimate strength, so this behavior could only be explained by increase in internal pressure due to disappearance of voids which might distribute the loads, so the melting down of the voids increased the internal pressure and thus escalating the rate of failure. So it should be noted that the MSW reject material without sand is less stiff, addition of sand increases stiffness but only to an extent so as not to affect the ultimate strength to decrease; similar to a bell shaped behavior. The graphical

interpretation of the variations of the Young's modulus of elasticity and the ultimate

strength to sand content and temperature are given below.
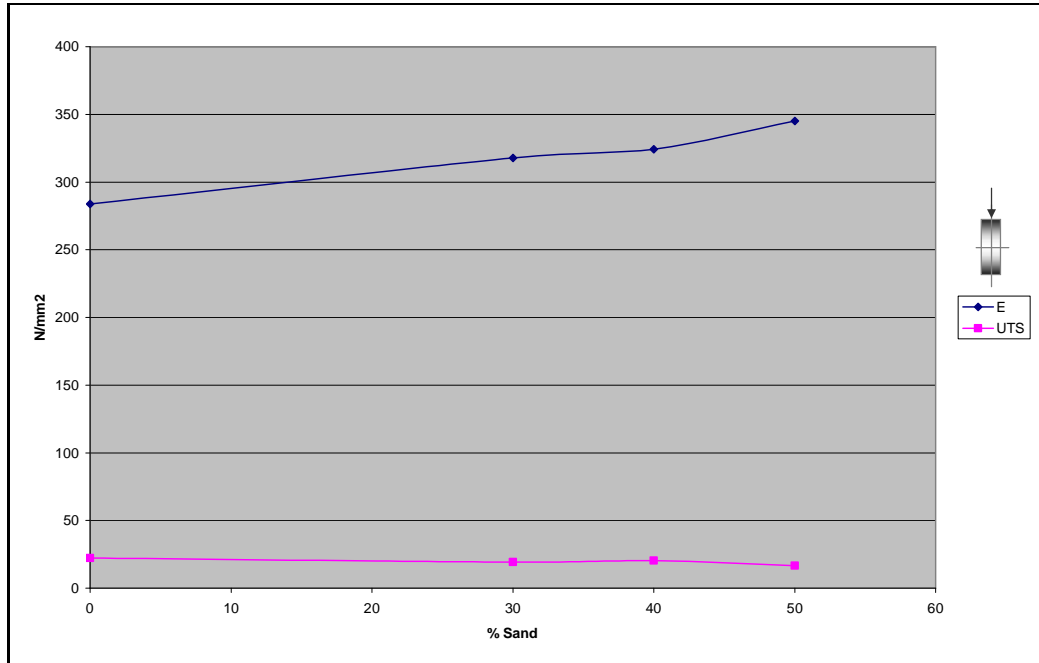
Figure 48: E & Ultimate Strength with Sand Content Variation mixed at 140°C
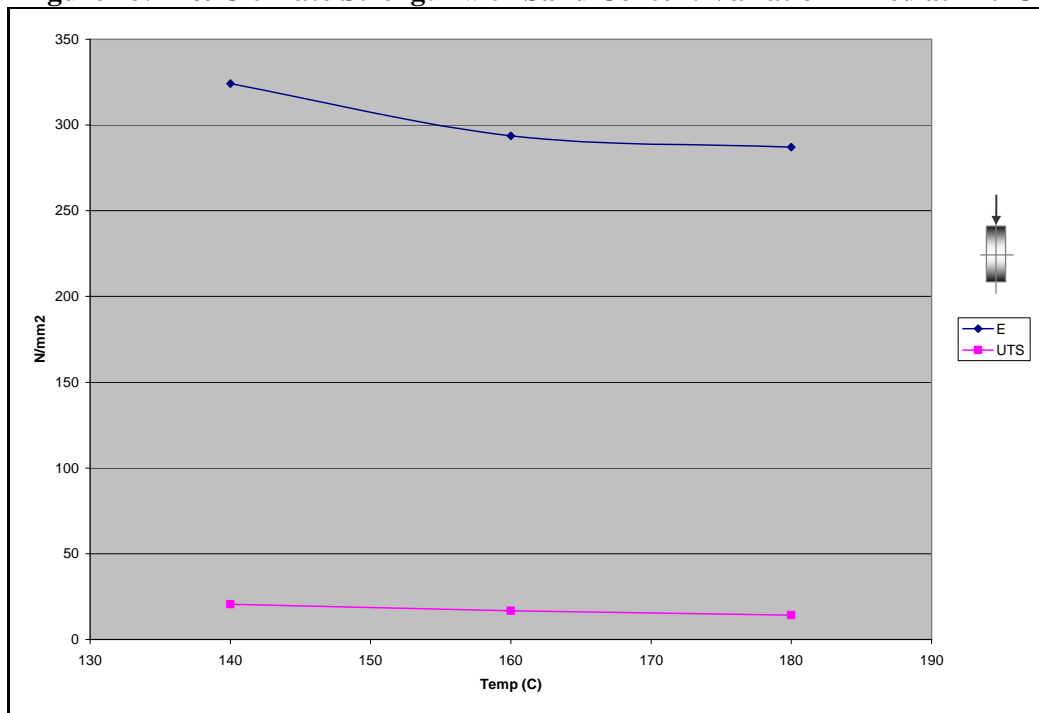
Figure 49: E & Ultimate Strength with Temperature Variation and 40% Sand Content

When applying a load perpendicular to the loading plane, Figure 46 & Figure 47 showed that the modulus of elasticity increases with the increase of the sand content, however, the zero percent sand resulted in a higher E; the table below shows the exact calculation for the slopes. The ultimate strength couldn't be properly interpreted in this loading direction because it was the maximum of the machine and not that of the samples.

Table 15: E and UTS with Sand Content Variation at 140°C (Parallel Loading)

Sand Content	Young's Modulus (MPa)	Ultimate Strength (Mpa)
0%	169.468	25+
30%	108.546	27+
40%	165.018	27+
50%	171.103	24+

The temperature impact on the modulus of elasticity in this loading plane didn't change much; the 40% sand mixed at 140, 160, & 180°C resulted in 165, 154, and 177 MPa respectively. Below are the graphical representations for the change of E with respect to sand content and temperature.
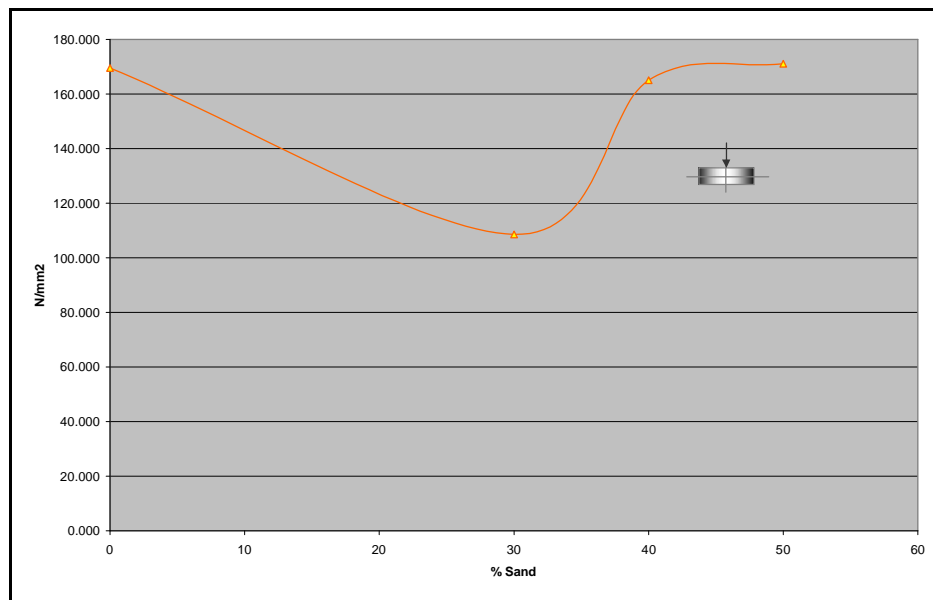
Figure 50: Modulus of Elasticity with variation of Sand Content at 140°C (Perpendicular Loading)

Figure 51: Modulus of Elasticity with variation of Sand Content at 140°C (Perpendicular Loading)

In order to identify the fractural strength of the sample in the perpendicular direction, loading was done using the machine in Figure 52, the sample failed at 732.2 and 760 KN respectively; for the 40 & 50% sand content sample. The maximum strength is calculated to be 44.3 & 47 MPa respectively. The samples exhibited an elastic behavior illustrated when the weight was removed; the compressed material regained some height again.

Figure 52: Fracture Machine

A source of error while performing this test on the MTS 800 is anticipated due to deformation of the loading plate noticed in the space between the shaft and the plate in Figure 53. The deformation was caused by the surface irregularities of the produced samples.

Figure 53: Deformation of Loading Plate on 810 MTS Machine

4.1.4. Abrasion

The procedure of this test was conducted as mentioned in Chapter 3; the samples were subjected to abrasion simulation using sea water media and chrome balls. The samples were loaded for 24 hours then the machine is stopped, and the samples are weighed in air and in water. Then the machine re-operates after 1 hour. The cycle was repeated four times, although the standards stated 72 hours testing, but the machine stopped during the last day due to electrical problems, so the whole cycle was repeated as it was difficult to know exactly when did the machine stopped. Table 16 shows the results and the volume difference during each cycle as per equations 6 & 7.

Table 16: Abrasion Test Results

	Sample	Weight in Air (gm)	Weight in Water (gm)	Volume Vt (m3)	Volume Lost (m3)
Cycle 0	1	490.94	30.3	0.0004620	0
	2	523.35	80.6	0.0004441	0
Cycle 1	1	492.94	38.3	0.0004560	6.01805E-06
	2	525.93	70.6	0.0004567	-1.26179E-05
Cycle 2	1	492.97	30.9	0.0004635	-1.4343E-06
	2	525.71	86.6	0.0004404	3.65095E-06
Cycle 3	1	490.96	33.9	0.0004584	3.59077E-06
	2	523.43	83.4	0.0004414	2.72818E-06
Cycle 4	1	493.03	33.2	0.0004612	8.12437E-07
	2	525.45	83.6	0.0004432	9.02708E-07

It is noted that the volume lost at the end of the cycles is fairly small, sample 1 lost about 0.176% of its original volume, while sample 2 lost about 0.2% of its original volume, the two samples did not loose significant volumes. The weighing of samples in water could be a source of error due to frequent flipping of digits.

4.2. *Weathering Tests*

4.2.1. Wet Dry Test

The test was conducted for the samples as per the ASTM standards, as the samples were immersed in water for 12 hours and then dried in an oven @ 60 to 70°C for 6 hours. The cycle was repeated 5 times. This test determines the percent loss as per equation 4. The results are given in Table 17 with averages calculations presented in Table 18.

Table 17: Data for Wet Dry Test

Mix	Sample #	Sand %	Temp °C	Weight Prior (gm)	Weight Dried (gm)	% Loss
Mix 1	4	30	140	1186.1	1185.86	0.02023
	5	30	140	1134.65	1134.45	0.01763
	6	30	140	1020.1	1019.88	0.02157
Mix 2	7	40	140	953.75	953.59	0.01678
	8	40	140	1336.76	1336.49	0.02020
	9	40	140	1125.36	1125.39	-0.00267
Mix 3	10	50	140	1291.6	1291.65	-0.00387
	11	50	140	1269.13	1269.36	-0.01812
	12	50	140	1179.6	1179.37	0.01950
Mix 4	13	40	160	1243.63	1243.26	0.02975
Mix 5	15	40	180	1246.65	1246.43	0.01765

Table 18: Average % Loss Distribution

Mix #	% Loss
Mix 1	0.0198
Mix 2	0.0114
Mix 3	-0.0008
Mix 4	0.0298
Mix 5	0.0176

It was noticed that sample 9 within Mix 2 gained weight in reference to the loss of samples 7&8; similarly sample 12 which lost weight opposite to the behavior of samples 10&11 that gained weight. This behavior is similar to the samples' behavior in the absorption test and thus could verify the hypothesis of sand clustering.

The percent loss is noticed to be very small, however it decreased with the increase of sand content, and this could be due to the fact that the increased filler material prevents samples from being dissipated leading to decrease in percent loss. When the mixing temperature is increased, some polyethylene bonds might have broken resulting in the increase in percent loss especially at the $160^{o}C$.

4.2.2. Soundness Test

The solution was supposed to cover the sample by 1/2 inch, but the samples floated. The 1st cycle was done by immersion of samples for 16 hours in the solution of Magnesium Sulfate followed by drying for 4 hours @ $60^{o}C$; however, the standards stated subjecting the samples to $110^{o}C$ for 2-4 hours. So in the 2nd cycle, the samples were subjected to $110^{o}C$ for 2 hours. The result was that the samples melted as shown below.

Figure 54: Melted Samples with Salt Precipitation

The test was repeated with new samples produced from rejects, so the sand content was not known (samples produced by APE). In addition to the fact that the

test was conducted for concrete to investigate salt reaction with gypsum; however, the MSW rejects are not expected to react with chemicals even when sand used. The samples were subjected to 16 hours immersion in the Sulfate solution and drying @ 50-60°C for 2 hours; the temperature was selected in reference to the Wet-Dry test and within operational temperature. In accordance to the ASTM standards, the percent loss was calculated and the data presented in Table 19.

Table 19: Soundness Test Data

Sample	Weight Prior (gm)	Weight Dried (gm)	% Loss
1	1273.57	1274.51	-0.074
2	1262.88	1264.04	-0.092

As speculated, the sulfate solution had no impact on the rejects, and no loss was determined, in fact, the samples gained some weight due to the sulfate precipitation.

4.3. Environmental Results

4.3.1. Exhaust Emissions

The test was conducted during the production of samples at 160°C. The results are presented in Table 20:

Table 20: Exhaust Emission Analysis Data

Parameter	Operation without Blower	Operation with Blower	Limits by Law [66] (mg/m3)
Flue Gas Temperature($^{\circ}$C)	214.4	184.7	
Combustion Air Temperature($^{\circ}$C)	32.3	32.3	
Volume % Oxygen	17.2	17.4	
Volume % CO_2	2.5	2.4	
Gross Efficiency	60.4	63.8	
Net Efficiency	65.3	68.9	
Carbon Oxide (ppm)	15 (88.8 mg/m3)	77 (481.25 mg/m3)	500
Nitrogen Oxides NOx (ppm)	16 (155 mg/m3)	12 (123 mg/m3)	400
Sulfur Dioxide (ppm)	0	0	350
Excess Air %	454	490.6	
Oxygen reference	3	3	

The following equations are used to calculate the CO and NOx in mg/m3:

$$CO_{mg/m3} = \frac{21 - O_{2ref}}{21 - O_2} \times CO_{ppm} \times 1.25 \qquad (9)$$

$$NOx_{mg/m3} = \frac{21 - O_{2ref}}{21 - O_2} \times \left[NO_{ppm} + NO2_{ppm} \right] \times 2.05 \qquad (10)$$

It is noted that all the exhaust emissions are below the limits set by the law; the carbon oxide increased when the blower was used as more exhaust is brought into the burning chamber without fully reacting. Excess air percent was also noticed to increase with operation of blower without affecting the carbon oxide. However, the nitrogen oxides decreased while operating the blower. Accordingly, the efficiency

increased from 65.3 to 68.9% on the account of increasing the carbon oxide which is approaching the limits.

4.3.2. Leachate

The sampled water was analyzed to evaluate the leachate from MSW reject products on water quality. Table 21 present the results. However, Toxicity Characteristic Leaching Procedure (TCLP) [55] was not followed, but the parameters are then normalized per mass of sample (Kg). The sample in sea water weighed 1342.81 & the sample in fresh water weight 1624.25 grams respectively.

Table 21: Water Analysis Result

Parameter	Original Sea Water	Sea Water after Experiment	Fresh Water after Experiment	Normalized Sea water (per Kg)	Norm. Fresh water (per Kg)	EPA[56]	TTLC [43] (mg/kg)	TCLP [43] (mg/l)
pH	7.99	7.83	8.05			6-9		
TSS (mg/l)	3	19	17					
TDS (g/l)	69.6	120.9	1.252	90.03	0.77			
Nitrate (mg/l)	0.44	3.96	0.88	2.95	0.542	10		
Nitrite (mg/l)	0.01	0.053	0.083					
COD			117		72.03	200		
Cadmium (µg/l)	2.7	0.8	1.5	0.596	0.924	40	100	1.0
Chromium (µg/l)	34.5	34.9	89.4	25.99	55.04	570	2500	5.0
Lead (µg/l)	50.2	234.6	36.5	174.71	22.47	210	1000	5.0

The results could not be compared to TTLC and TLCP limits because procedure was not followed. However, for sake of discussion, results are compared to EPA surface water discharge criteria. The TDS in the sea water was nearly doubled due to evaporation of sea water (more than 50-70% evaporated), thus salt concentrated leading to the increase in TDS of the sea water sample.

The COD was noticed to be within the EPA limits of 200 mg/l.

The heavy metals are within Egyptian limits for discharge on surface water; however, lead in sea water was slightly higher than the EPA limits.

It is also important to note the inconsistency of contamination of rejects from various sources in landfills, so it would be advisable to wash the rejects prior to processing such that the washing water could then be treated, and thus ensuring minimal toxicity leaching to the surface water.

An increase in weight of 0.2 and 0.3% was noticed after sample immersion for 28 days in fresh and sea water respectively.

4.4. Comparison of Properties to Concrete and PE

In order to properly evaluate the performance of the reject material as erosion protection structures, the properties revealed from the various tests are compared to concrete bricks, HDPE and LDPE in Table 22. The proposed material is to be used as:

1. Floating breakwater
2. Armour unit submerged breakwater
3. Beach revetment
4. River/canal bank revetment

Figure 55: Floating Breakwater (*UpLeft*), Beach Revetment (*Up Right*), Rock Breakwater (*Down Left*), and Concrete Canal Revetment (*Down Right*)

Table 22: Mechanical Properties Comparison

	MSW Reject Material						LDPE [46]	HDPE [46]	Concrete Brick [65,7]
	Mix 0	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5			
Specific Gravity	0.984	1.102	1.140	1.179	1.145	1.146	0.917-0.931	0.943-0.963	2.2-3.0
Density (gm/cm3)	0.981	1.099	1.137	1.176	1.142	1.143	0.914-0.928	0.94-0.96	2.24-2.4
Absorption %	0.127	0.386	0.440	0.578	0.250	0.245	0.01	0.01	11-13* / 16-18 **
E (N/mm2)	283.91	317.9	324.2	345.22	293.75	287.11	200-500	700-1400	
UTS (N/mm2)	22.22	19.37	20.48	16.63	16.80	14.21	8-23	18-35	17/24
%Loss (Wet/Dry)	---	0.0198	0.0114	-0.0008	0.0298	0.0176			0.5

* Compared to Drain Water Tiles [11]
** Molded Bricks [14]

It is noted that the densities of the MSW reject material through out all the mixing ratios are higher than the nominal PE whether low or high density; however, when compared to concrete, the MSW reject material possesses lower specific

gravities, which makes them lighter in weight when used as submerged structures as high specific gravities are preferred [91].

The absorption percent of all mixes are lower than the approved ASTM specification for concrete tiles or molded bricks. However, the specification for absorption percent of LDPE and HDPE are lower than all the mixing ratios. The increase in absorption leads to increase in densities which allow higher sand content to be utilized as submerged structures because of the increase in weight initiated with the absorption process.

The stiffness of all the mixes was found to be within the range of the LDPE.

The ultimate strength is within the high range of LDPE, mid range of HDPE and Concrete specifications. So all applications utilizing these materials are applicable to MSW reject material.

The percent loss during the weathering test for all the mixings was much lower than the approved ASTM specifications of concrete bricks.

Table 23: Function Properties Comparison

	MSW Rejects		Concrete Brick [14]
	Sample 1	Sample 2	
Soundness Loss %	-0.074	-0.092	0.5
Abrasion Loss (cm3/cm2)	0.0052	0.0058	1.7-4.0

The functional properties are compared to concrete bricks, the sulfate had no impact, the samples did gain weight and that is opposite to the specifications. Accordingly, salt operation conditions are of no impact on the MSW reject material.

The abrasion loss of the material was also lower than the allowed limits for concrete bricks so the material is recommended for abrasion operation conditions.

Accordingly, the MSW rejects material possesses excellent properties throughout the proposed functional specifications, and the material could successfully be utilized as floating breakwater or floating platoons, breakwater armour units (regular of irregular shaped), and bank/canal/beach revetment tiles.

Presented in the next chapter are the major findings and conclusion, followed by recommendations for further investigation of additional applications and modifications.

CHAPTER FIVE
CONCLUSION & RECOMENDATIONS

The work throughout this thesis aims at trying to solve MSW mismanagement schemes, and utilizing MSW rejects in producing shoreline erosion protection structures. The structures as breakwaters (floating or submerged) and revetments would enhance the country's solid waste management performance and act as a line of defense against the impacts of sea level rise as a result of climate change and global warming.

5.1. Major Findings

The MSW rejects samples were produced of different sand mixes ratios at different temperatures. The MSW rejects are characterized with various properties that differ in accordance to the proposed usage. The following is a summary for the major findings in regards to the proposed structural functions.

5.1.1. Floating Breakwater

Floating breakwaters are usually made of HDPE, so conclusions on usage are based on comparison of properties resulting in the following:

§ The zero percent sand content floats over water and has a very low absorption rate compared to other mixing ratios, 67% less than the following absorption rate of the 30% sand mix.

§ The density of the zero percent sand is higher than the HDPE by 2%.

§ The zero percent MSW reject mix is less stiff by 59% thus reacting better to sudden loads.

§ The ultimate strength of the zero percent sand is higher than the lower limit of HDPE by 23%.

§ The absorption rate of the zero percent mix is very poor compared to HDPE, so protective coating is to be further investigated.

Accordingly, usage of zero percent sand mix in the production of MSW reject product as a floating breakwater is recommended. However, foam injection could be investigated and utilized to substitute for the relatively high absorption rate in this mixing ratio compared to HDPE.

5.1.2. Breakwater

Breakwaters or armour units used in submerged structural breakwaters as mentioned in chapter 2 are made of concrete and newly improvements include usage of HDPE in particular designs, so the following concerns were noticed while comparison of the MSW rejects to the concrete properties.

§ This usage required higher specific gravity illustrated in the 50% sand mix which is 33% higher than the 40% sand mix and 65% higher than the 30% sand mix. Using $40^{o}C$ higher temperature resulted in an increase of 40% mix specific gravity by 0.5%.

§ The modulus of elasticity of the 50% sand mix is 6% higher than 40% sand mix and 8% higher than the 30% sand mix; temperature negatively impact this property as the 40% sand mix modulus decreased by 9.5 & 11.5% respectively at 160 and $180^{o}C$.

§ In regards to strength, the 40% mix was found to be 19% higher than 50% sand and only 5% higher than 30% sand mix; while in this criterion the temperature did not add much this property.

§ Specific gravity/density of the mixes is less than that of concrete by 25+% (compared to the 50% sand mix, the highest density).

§ The absorption is less than concrete by more than 95% (compared to the 50% sand mix, the highest density).

§ The 40% sand mix is higher than the lower limit required for strength of concrete by 17%; the 50% sand mix is lower than the lower limit by 2.2%; however, temperature increase would only lead to further deterioration of the property as 40% sand mix decreased by 18% at an increase of 20°C.

From all the above and while the 50% sand mix is superior in terms of specific gravity and the stiffness modulus, but the compressive strength is more important. So the 40% sand mix is suitable, while increasing the temperature would increase specific gravity on the account of other properties. To overcome the weigh issue, usage of perforated armor units should be further investigated. It should be noted that the specific gravity of irregular shapes (in case used) is 5% less than compacted MSW reject paste.

5.1.3. Beach/Canal Revetment

Revetment tiles are used to stabilize beaches and river/canal banks. The revetments are sometimes made of rock, concrete bricks or molded bricks, so conclusions on usage were based on comparison of the MSW rejects to the concrete properties. In lieu of the issues mentioned in section 5.1.2, the strength of the 50% sand mix is compared to data for loading perpendicular to the plane, and the result is higher than the required strength of pavement tiles by minimum of 30%. In addition to the superior performance while wet-dry test very slight weight gain of 0.001%

overcoming the specified loss of 0.5%. Thus, the 50% sand mix is suitable for such usage.

5.2. Recommendations for Future Research

5.2.1. Potential Applications

The following presents additional potential applications for further investigation and research whenever applicable:

§ ***Interlocking ground reinforcement tiles*** [73]: the MSW rejects are characterized by superior compressive strength, and good absorption percent, reaction to chemicals is also anticipated to be good when taking the PE properties in consideration, so ground reinforcement tiles would be recommended, however, further studies might be needed to test reaction with compost if used in landscaping. Figure 56 illustrates the usage of interlocking tiles as ground support.

Figure 56: Interlocking Mats

§ ***Reef Ball*** [76]: A Reef Ball is a designed Artificial Reef used to restore ailing coral reefs and to create new fishing and scuba diving sites. Reef Balls are used for beach protection, freshwater, mitigation, and many

other usages. Reef Balls are made of concrete into a fiberglass mold containing a central polyform buoy surrounded by various sized inflatable balls to make holes. [76] Figure 57 illustrates the orientation of various reef balls to act as breakwater. (Installed in the Dominican Republic)

Figure 57: Reef Balls

§ *Artificial reef:* similar to the manner of reef balls, the point is utilizing the plastic rejects in coral like forms to enhance the microbial growth and provide fishery grounds.

Figure 58: Artificial Reef [39]

5.2.2. Modifications & Further Investigations

§ Sealer coating could be investigated for usage for prevention of Algae growth.

§ Usage of activated carbon for VOC in furnace.

§ Further investigation for bacterial growth.

§ Addition of color pigments could enhance the aesthetic negative impact. The colors should not contain any heavy metals.

§ Fixation: the following is a patented system [74], which consists of elements for absorption of tension and compression. The system mold could be modified for application of thus fixation system.

Figure 59: Fixation Patent [74]

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