OPTIMIZATION OF POLYETHYLENE TEREPHTHALATE RESIN-BRICK FORMULATION AND DESIGN ANALYSIS FOR SUSTAINABLE CONSTRUCTION MATERIAL

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DEDICATION

To my wife, mother and beloved family

Fina Yuni Farida

Sarliyah

Eroh

"Thank you for your patience and support"

ABSTRACT

Construction materials have embraced the use of recycled and renewable materials to meet sustainability goals, including plastic waste in the construction sector. One such use is in the creation of eco-bricks, which are environmentally friendly bricks made from waste materials. The primary raw material used in making eco-bricks is waste materials. With the increasing population and urbanization, plastic waste is on the rise and further processing is necessary to produce eco-friendly products like eco-bricks. However, a weakness in making eco-bricks lies in the adhesive or mixture used. Currently, some eco-bricks still use cement or clay as a binder, which requires further processing for drying and to increase compressive strength. A solution to this is using another type of adhesive that can improve the strength of eco-bricks, such as epoxy resin. Epoxy resin has high strength, durability, and the ability to protect against corrosion. It is also flexible and can be easily applied to different surfaces and with other materials. Therefore, in this research, a new type of eco-brick is made, namely PET-resin brick (PR-brick). PR-bricks are made using another type of adhesive, epoxy resin. The aim of this research is to optimize the material formulation and processing variables of PR-brick production and validate the performance, analyze the mechanical and thermal properties of the PR-brick and last is analyze environment impact of the production process of PR-brick. The method used in this research is RSM for formula optimization and processing variables of PR-brick. After the accuracy evaluation, PR-brick performance optimization statistical model has been developed. In this experiment Factor of Safety (FoS) and thermal properties were carried out on a base stand using Finite Element Method (FEM). The structural design and FEM analysis was carried out using SolidWorks software. In addition, LCA analysis is also used to analyze the impact of PR-Bricks on the environment. LCA Analysis adopted a gate-to-gate approach. This research aligns with the sustainable development goals (SDGs) program by promoting the use of environmentally friendly products through recycling. For the RSM is to determine the optimal mixture proportions in terms of ratio (%), particle size (mm), and drying time (days). The results show that the most suitable parameters for PR-brick production are a PET particle size of 1.14 mm, a mixing ratio of 89.97% and 6.92-days drying time based on RSM. Size 200x100x100 mm has a maximum FoS value than other shape. Size 200x100x100 has a value 6.544 for FoS. From the LCA PR-brick use of epoxy resin and PET as raw materials for eco-tiles has an impact on ozone formation (OF) of 118 m^2 UES*ppm*hours, which is due to the use of epoxy resin chemicals as adhesives in the production of PR-Brick. The research indicates that this material mixture has a high potential for improving the compressive strength of PR-Brick. The results of the study indicate the use of epoxy resin and recycled PET in PR-Brick production does not pose excessive environmental risks and does not significantly reduce the environmental profile.

PENGOPTIMUMAN FORMULASI DAN ANALISIS REKABENTUK RESIN POLIETILENA TEREFTALAT-BATA UNTUK BAHAN BINAAN LESTARI

ABSTRAK

*Bahan binaan telah menerima penggunaan bahan kitar semula dan boleh diperbaharui untuk memenuhi matlamat kemampanan, termasuk sisa plastik dalam sektor pembinaan. Salah satu penggunaan sedemikian adalah dalam penciptaan eko-bata, yang merupakan bata mesra alam yang diperbuat daripada bahan buangan. Bahan mentah utama yang digunakan untuk membuat eko-bata adalah bahan buangan. Dengan pertambahan penduduk dan pembandaran, sisa plastik semakin meningkat dan pemprosesan selanjutnya adalah perlu untuk menghasilkan produk mesra alam seperti eko-bata. Walau bagaimanapun, kelemahan dalam membuat eko-bata terletak pada pelekat atau campuran yang digunakan. Pada masa ini, beberapa eko-bata masih menggunakan simen atau tanah liat sebagai pengikat, yang memerlukan pemprosesan lanjut untuk pengeringan dan untuk meningkatkan kekuatan mampatan. Penyelesaian untuk ini ialah menggunakan pelekat lain yang boleh meningkatkan kekuatan eko-bata, seperti resin epoksi. Resin epoksi mempunyai kekuatan tinggi, ketahanan, dan keupayaan untuk melindungi daripada kakisan. Ia juga fleksibel dan boleh digunakan dengan mudah pada permukaan yang berbeza dan dengan bahan lain. Oleh itu, dalam penyelidikan ini, satu jenis eko-bata baru telah dibuat iaitu bata PET-resin (bata-PR). Bata PR dibuat menggunakan jenis pelekat lain, resin epoksi. Matlamat penyelidikan ini adalah untuk mengoptimumkan pembolehubah rumusan dan pemprosesan bahan pengeluaran bata-PR dan mengesahkan prestasi, menganalisis sifat mekanikal dan haba bata-PR dan akhirnya menganalisis kesan alam sekitar proses pengeluaran bata-PR. Kaedah yang digunakan dalam penyelidikan ini ialah kaedah rangsanganpPermukaan (RSM) untuk pengoptimuman formula dan pembolehubah pemprosesan bata-PR. Selepas penilaian ketepatan, model statistik pengoptimuman prestasi bata-PR telah dibangunkan. Dalam eksperimen ini Faktor Keselamatan (FoS) dan sifat terma telah dijalankan pada dirian tapak menggunakan kaedah elemen terhingga (FEM). Reka bentuk struktur dan analisis FEM telah dijalankan menggunakan perisian SolidWorks. Selain itu, penilaian kitaran hayat (LCA) juga digunakan untuk menganalisis kesan bata-PR terhadap alam sekitar. Penilaian LCA menggunakan pendekatan pintu ke pintu. Penyelidikan ini sejajar dengan program matlamat pembangunan mampan (SDGs) dengan mempromosikan penggunaan produk mesra alam melalui kitar semula. Untuk RSM adalah untuk menentukan bahagian campuran optimum dari segi nisbah (%), saiz zarah (mm), dan masa pengeringan (hari). Keputusan menunjukkan bahawa parameter yang paling sesuai untuk pengeluaran bata PR ialah saiz zarah PET 1.14 mm, nisbah campuran 89.97% dan masa pengeringan 6.92 hari berdasarkan RSM. Saiz 200x100x100 mm mempunyai nilai FoS maksimum daripada bentuk lain. Saiz 200x100x100 mempunyai nilai 6.544 untuk FoS. Daripada LCA bata-PR penggunaan resin epoksi dan PET sebagai bahan mentah untuk eko-jubin memberi kesan kepada pembentukan ozon (OF) sebanyak 118 m2 UES*ppm*jam, yang disebabkan oleh penggunaan bahan kimia resin epoksi sebagai pelekat dalam pengeluaran bata-PR. Penyelidikan menunjukkan bahawa campuran bahan ini mempunyai potensi tinggi untuk meningkatkan kekuatan mampatan bata-PR. Hasil kajian menunjukkan penggunaan resin epoksi dan PET kitar semula dalam pengeluaran bata-PR tidak menimbulkan risiko alam sekitar yang berlebihan dan tidak mengurangkan profil alam sekitar dengan ketara.*

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

E	-	Modulus elasticity
AP	-	Acidification Potential
CE	-	Circular Economy
OF	-	Ozone formation
PC	-	Polycarbonate
PP	-	Polypropylene
PS	-	Polystyrene
PU	-	Polyurethane
BMI	-	Body Mass Index
CAD	-	Computer Aided Design
CCD	-	Central Composite Design
DoE	-	Design of experiment
ECH	-	Epichlorohydrin
EDX	-	Energy Dispersive X-ray
EPA	-	Environmental Protection Agency
FEA	-	Finite element analysis
FEM	-	Finite Element Method
GWP	-	Global warming
ISO	-	International Organization for Standardization
LBP	-	Low Back Pain
LCA	-	Life Cycle Assessment
LCI	-	Life Cycle Inventory
MFR	-	Melt Flow Rate
NBM	-	Nordic Body Map
OPC	-	Ordinary Portland cement
PET	-	Polyethylene terephthalate
POF	-	Photochemical ozone formation
PVC	-	Polyvinyl chloride
RBD	-	Red brick dust

RSM	-	Response Surface Method
SEM	-	Scanning Electron Microscopy
SNI	-	Indonesian Standard (Standar Nasional Indonesia)
SOD	-	Stratospheric ozone depletion
STS	-	Socio-technical System
TDH	-	Terephthalic dihydrazide
WHO	-	World Health Organization
ASTM	-	American Society for Testing and Materials
CBWM	-	Community-based waste management
EDIP	-	Environmental Design of Industrial Products
HDPE	-	High-Density Polyethylene
HSEG	-	Higher SocioEconomic Group
LCIA	-	Life Cycle Impact Assessment
LDPE	-	Low density polyethylene
LSEG	-	Lower SocioEconomic Group
MSDs	-	Musculoskeletal Disorder
MSEG	-	Middle SocioEconomic Group
NGOs	-	Non-Governmental Organizations
PUPR	-	Ministry of Public Works and People Housing
DGEBA	-	Diglycidyl ether of bis-phenol A
ANOVA	-	Analysis of variance

LIST OF SYMBOLS

x_i; x_i ; x_i;	-	Indepedent variables of factors
β_0; β_i; β_{ii}; β_{ij}	-	Regression coefficient
ε	-	Strain
σ	-	Stress

LIST OF APPENDICES

LIST OF PUBLICATIONS

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CHAPTER 1

INTRODUCTION

1.1 Overview

This chapter describe the formulation of the problem. This introductory chapter explain the research rationale, research question, objective, and the scope of the research.

1.2 Research Background

Bricks have been known since the earliest civilizations (Kadir and Mohajerani, 2011. Bricks are one of the most sought-after materials used in building construction (Afzal et al., 2020). Bricks are made of clay and sand mixed in appropriate proportions by adding a binder (Murmu and Patel, 2018). Brick is one of the common and widely used products in buildings (Muntohar, 2011). Unfortunately, in the last 20 years, the market for brick products in construction has reached a saturation point (Crespo-López and Cultrone, 2022). Therefore, the brick manufacturing industry is diversifying its products by utilizing waste as an additional ingredient in brick manufacturing (Adazabra et al., 2023; Ramakrishnan et al., 2023).

One way to develop the concept of green ecology and energy conservation is to make permeable bricks (Antunes et al., 2018; Wang et al., 2019; Shafiquzzaman et al., 2022). Permeable bricks have advantages including reducing the effect of heat, absorbing noise, and improving the anti-skid performance (Smith et al., 2001). One way to make permeable bricks is to use additional plastic waste. This plastic waste will make it eco-friendly (Zhou, 2018)

Waste can cause problems in the environment, including soil pollution and causing a dirty environment, and it also has an impact on health (Kholil and Jumhur, 2018; Tekler et al., 2019). Nowadays, the amount of waste is increasing along with the increases in population, activity level, life pattern, socio-economic level, and technological progress, growing increasingly (Xue, Cao and Li, 2015). Waste needs to be managed in order to be used as part of a useful product. Waste management has become an important issue in recent years. Waste management is required to identify the source of waste, how waste management is appropriate, and the design of the waste treatment equipment. Inorganic waste such as paper or plastic can be recycled and significantly contribute to the economy of the community (Daspereira, and Fernandino, 2019; Yusuf et al., 2019).

Waste can trigger ecological problems such as a filthy environment, soil pollution, and health concerns (Kholil and Jumhur, 2018; Owusu-Nimo et al., 2019). Furthermore, waste harms the environment (Ishak et al., 2018). The volume of waste is likely to increase with the rise in the populace, as well as changing life patterns, socio-economic level, activity level, and technological advancements (Setyowati and Mulasari, 2013; Boysan et al., 2015; Mohamad et al., 2019). Waste has to be managed so then it can be used as a worthwhile product. This has emerged as a key concern in recent times (Boysan et al., 2015).

Waste can be classified into organic and inorganic waste (Anjum et al., 2022). Inorganic waste like plastic or paper can be recycled and go on to make a considerable contribution to the economy (Asteria and Heruman, 2016; Ishak et al., 2017).). One of the concerns faced by emerging nations such as Indonesia is the management of waste (Abdel-Shafy and Mansour, 2018a). Plastic waste, which is dangerous and tough to manage, is a key aspect that causes ecological harm. This continues to be a concern for Indonesians (Lestari and Trihadiningrum, 2019; Fatimah et al., 2020; Kamaruddin et al., 2022). Plastic bags, a widely-used commodity for people around the world, when discarded, take tens and sometimes hundreds of years to disintegrate (Utami et al., 2019). To mitigate the critical problem of plastic waste, recycling is a necessary measure. The efficacy of inorganic waste recycling initiatives can be impacted by many aspects like appropriate service facilities and the efficient management of waste. Waste management begins with waste sorting and gathering, followed by processing (Boysan et al., 2015).

The recycling process can be categorized into four types, namely primary, secondary, tertiary and quaternary recycling (Neo et al., 2021). Primary recycling is also known as closed-loop recycling where plastic waste products are recycled back into the same product. Secondary recycling is known as open-loop recycling, where plastic waste is converted into other products. Tertiary recycling is also known as raw material recycling, where chemicals break down the plastic into monomers or other small molecules. Finally, quaternary recycling involves energy changes where waste is burned to become energy. In this research, the polyethelen (PET) recycling process uses open-loop recycling, where PET waste is developed into a composite called an eco-brick. This eco-brick is a mixture of PET particles and epoxy resin. Composite materials will provide excellent strength with resulting mechanical properties of being lightweight, having a resistance to corrosion, and high durability (Junid et al., 2021).

PET is the plastic used to make bottles and containers. Recently, efforts have been made to use the plastic waste generated in different applications in civil engineering to divert the amount of plastic waste going to landfills. The addition of plastic waste to granular pavement material can significantly affect the strength and deformation properties of said material, which needs to be fully understood before its widespread use in the construction of pavement/subbase layers (Ghorbani et al., 2021). The utilization of plastic waste can be used as a mixture for making bricks. The types of plastics widely used to make plastic bricks include PET, LDPE, and HDPE (Bhushaiah et al., 2008; Sellakutty, 2016; Akinwumi et al., 2019; Intan and Santosa, 2019; Limami et al., 2020a).

Material selection is essential in building construction because it impacts building performance. Suitable materials can help to reduce the energy contained in the building (Venkatarama Reddy and Jagadish, 2003; Thormark, 2006; Cherian et al., 2020). In addition, the correct selection of materials will also affect carbon dioxide emissions into the environment, energy use in the production process, environmental impacts during the life cycle, energy consumption, and air quality disturbances (Florez and Castro-Lacouture, 2013). Several factors such as cost, mechanical properties, environmental performance, physical properties, and safety are often included as part of making the material so then it is optimal (Giudice et al. 2005; Abeysundara et al. 2009; Chen et al., 2019; Ferrari et al., 2020; Ilbeigi et al.2020).

Currently, the brick industry contributes significantly to environmental degradation (Ahmed, 2023). The firing process in brick manufacturing emits about 70-282 g of carbon dioxide, 0.001-0.29 g of black carbon, 0.29-5.78 g of carbon monoxide (CO), and 0.15-1.56 g of particulate matter per kilogram of brick burned, depending on the type of kiln and fuel used. In addition, it consumes about 0.54-3.14 MJ of specific energy per kilogram of bricks produced, depending on the type of kiln and fuel (Barros et al., 2020a). Therefore, it is necessary to produce environmentally-friendly bricks by not using the firing process.

Industries and communities are developing environmentally friendly bricks (Anjum et al., 2022). Bricks made from a mixture of waste are being widely-developed, ranging from organic to plastic waste (Chua-Chil et al., 2012; Akinwumi et al., 2019). PET bottles are filled with clay and then arranged into buildings. One advantage of this brick model is that the cost of the eco-bricks is zero because they use leftover materials and waste from around the environment. However, there is a drawback of bricks made from PET bottles, which is that they are prone to fire. Edike (2020) and Chien et al.'s (2022) research also discuss eco-bricks containing PET bottles and tiny plastic pieces (Edike et al.2020a; Mei Chien et