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The Efficiency of Waste Materials in Eco - Concrete

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Abstract : Eco-concrete is a building material that multiple research were completed. Thus, require to know the most waste materials for producing potential good eco–concrete variations and build a calculation system for the production of eco–concrete which is the construction industry needed as a facility medium. Waste material that used are waste glass, Polyethylene terephthalate (PET), fly ash (FA) and rice husk ash (RHA). This studies will discuss about the waste materials used in eco – concrete in terms of comparison optimal percentage replacement for observe the performance and efficiency that affected on mechanical properties of eco – concrete and also eco – concrete calculation system as new potential innovation system. Mechanical properties and an eco – concrete calculation system will be as a benchmark to compare all the waste material in this study. The maximum researched paper for this study is 30 papers in discussion and using critical review that was involve method of data collection and data analysis to point out what is the possible optimal percentage replacement of waste material used in Eco - concrete. The range of sources such as article journals used is from 2003 until 2021. Practical method was applying during built eco – concrete calculation system with main function is to obtain the ratio and volume of cement, sand, aggregate, and also waste materials needed to produce an eco-concrete for use in industry. Based on studies, waste glass with 10% optimal percentage replacement as potential waste materials that can produce the good quality of eco – concrete in terms of improvement in compressive, tensile and flexural strength.

Keywords: Eco - Concrete, Waste glass, Polyethylene Terephthalate (PET), Fly Ash, and Rice Husk Ash

1. Introduction

Eco-concrete is a building material that is increasingly known and even there is construction abroad that applies it but in Malaysia clearly know most of the research done on it. Nevertheless, the effectiveness of the eco - concrete produced needs to be evaluated and analysed before being applied in

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industry. According to the issue of this studies, the term efficiency of waste materials is result when waste materials used in concrete that will give huge impact in production the good sustainable materials in construction industry. The efficiency observed from comparison optimal percentage of waste material replacement that will give effect on mechanical properties of concrete. Originally, conventional concrete existed before the eco - concrete. Generally, terminology of concrete is a composite man made material that make from water, aggregate and also Portland cement as a three basic component. While the definition of eco – concrete is an evolution of concrete which apply recycled materials. Terms eco in this studies refer to combination of economic and environmental performance in concrete. Thus, among the materials for making this eco - concrete are Poly Ethylene Terephethalate (PET), rice husk, fly ash and waste glass. Eco-concrete also has its own advantages which will influence the process and management of construction such as good thermal resistance when mixed with concrete [1] environmental friendly and economical.

In addition, different types of waste materials mix in concrete will influence the mechanical properties of eco – concrete such as bring a lot of loading, strength, long-lasting and others. Thus, although various studies have been done, what wastes are most widely used and have the potential of best impact on eco-concrete manufacturing? The real question is how effectively the waste materials applied in the eco-concrete produced will be beneficial? Besides, eventhough multiple research of eco – concrete was done but what are the ways or systems that can facilitate the process of eco - concrete production. Therefore, the waste materials for producing potential great eco – concrete variations should be studied and calculation system for determine amount of component in eco – concrete must be introduced.

1.1 Objective of this studies

The objective of this studies are as follows:

i. To identify the most potential waste materials applied eco-concrete in research by compare the optimal percentage replacement for observe the performance and efficiency in terms effect on mechanical properties of eco - concrete.

ii. To build a calculation system for the production of eco - concrete as a facility medium in the construction industry by applying suggestion optimal percentage replacement of waste materials.

1.2 Scope and limitation

This study focuses on reviewing effectiveness of waste material in eco concrete. The information collection will be conducted by gathering various type of document such as article journal, research paper and book about waste material such as PET, rice husk, waste glass, and fly ash through year 2003 until now. The study will consider of what is the optimal waste material use in eco concrete and evaluate each waste material mechanical properties. Eco - concrete calculation was execute to make it easier for the construction industry to estimate the ratio of each material to produce the strong eco – concrete.

2. Methodology

The objective of this study is to identify the most potential waste materials applied eco-concrete in research by compare the optimal percentage replacement for observe the performance and efficiency in terms effect on mechanical properties of eco – concrete and also build a calculation system for the production of eco - concrete as a facility medium in the construction industry by applying suggestion optimal percentage replacement of waste materials. Method of data collection to provides the data needed were using. Definition method of data collection is the instrument type from collection information and data of article or journal about the percentage of making the eco-concrete using waste such as fly ash, Polyethylene terephthalate (PET), rise husk and waste glass. Besides, method of eco – concrete design as medium to run for get the suitable ratio and volume of each component to built eco

– concrete was used. Both methods use in this study are involve qualitative and quantitative approach. The critical review process involve qualitative approach which is a method that is mostly expressed in words in other means is non-numerical and the quantitative approach is a method of data analysis where including numbers and graphs. This kind of method is using for assumptions and conclusions from number of sources such as article journals and research paper that were analyse. After that, the practical method that applied in eco – concrete calculation by through Microsoft Excel which is involve quantitative approach also used. As illustrated in **Figure 1** shows the flowchart of this studies.

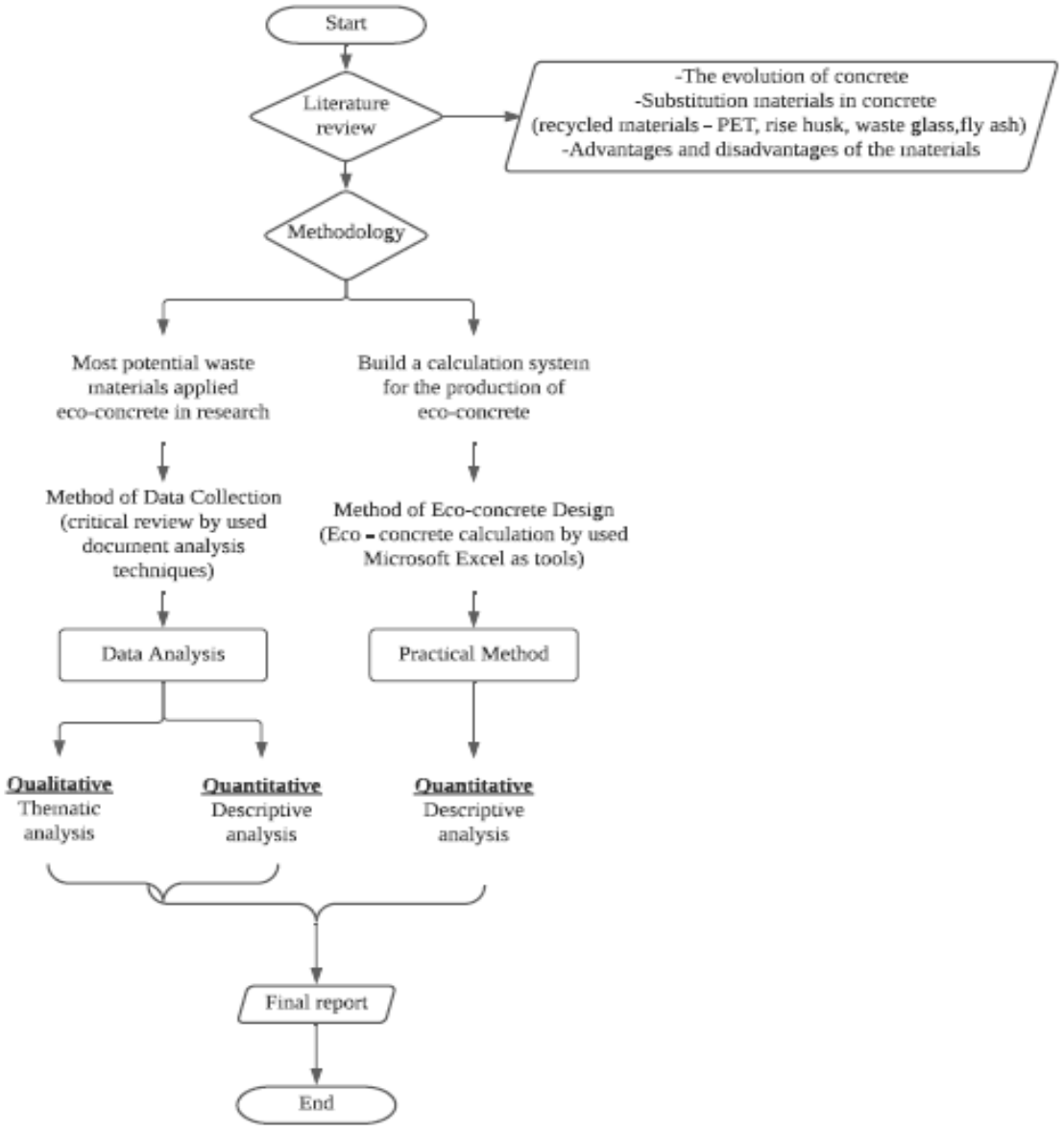

Figure 1: Flowchart of this study

2.1 Method of data collection

Terminology of data collection is the process of collecting and quantify information from all relevant sources on variables of interest, in set of systematic fashion that allow one to answer mentioned research questions, test hypotheses and analyst the outcome [2].

2.1.1 Document analysis

Document analysis is a method based on secondary data. Various information research platforms have been accessed such as Google Scholar, Science Direct, Academia.edu, Research Gate and etc. Through this platform, the data was collect for this study from research materials such as journals, books, review article, research article and etc. This method is used to help the addition of information, especially for literature review and to achieve the objectives of which this method is very helpful in writing critical review. Critical review is related to the comparison in terms of number of application, optimum percentage replacement and performance observation in terms of mechanical properties of waste materials used in eco – concrete. In critical review, 30 article journals around range 2003 until 2021 were collected then reviewed. Based on the 30 journals collected, nine article journals on waste glass, six article journals on PET, six article journals on fly ash, five journal articles on rice husk ash and four journal articles where waste material is mixed with other materials.

2.2 Method of Eco – Concrete design

Method of Eco – Concrete design is a process of calculate mix ratio of the eco –concrete component by using formula and specifically format that designed in Microsoft Excel. In this method, estimation techniques are applied to determine the percentage content of waste material to be used. The determination percentage of the waste material content plays a very important role which will affect the ratio and volume required to produce eco - concrete. Therefore, the determination should be based on the user's own knowledge of which the proposed percentage can be estimate through comparison optimal replacement between different waste materials with efficiency observation on mechanical properties view.

2.2.1 Eco – Concrete calculation by Microsoft excel as tools

Table 1: Template format for Eco – Concrete calculation

Percentage component in eco - concrete

Sand	Cement	Aggregate	Waste material	Total
18.2	27.3	34.5	20	100

Ratio component in eco concrete

Cement	Sand	Aggregate	Waste material	Total
1.5	1.0	1.9	1.1	5.5

Concrete dimension

Width (cm)	Length(cm)	Height(cm)	Total (cm^3)
10	10	10	1000

Volume for each component that needed in eco - concrete (cm^3)

Cement	Sand	Aggregate	Waste material
273.0	182.0	345.0	200.0

Eco – concrete calculation show in **Table 1** is built to obtain the amount of cement, sand, aggregate and also waste materials needed to produce an eco-concrete for use in industry. This actual calculation can be categorized as quantitative method. A several formula that present at result and discussion section was applied in this calculation then was calculate just by through Microsoft excel. The function

that used in excel is sum. The concept of this calculation is ratio to find the right amount of volume each material in produce the eco – concrete. This eco – concrete calculation is divided to four section that started by calculate percentage of each material which is to find total percentage, the user need to remember that when waste material is added, the user need to calculate first the new percentage aggregate which is should be minus by the percentage of waste material. Then, followed by second section which is to find the ratio of each material by fixed total ratio for concrete was given. After that, the third section is depends on user to built eco – concrete with any suitable dimension but in this case fixed to 1000 cm^3. The third section is related to the last section which is to determine the volume of each material needed that depends on the dimension of eco – concrete to built.

2.3 Method of data analysis

The act of efficiently applying factual and sensible devices to depict and show, pack and investigate information is known as data examination. A critical review is considerably more than a fundamental synopsis and it's anything but a careful assessment and examination of a book, article, or other medium. In this studies, critical review conducted by several process which is started from article research and collected. Then, the screening and refine were perform based on observe the methodology, laboratory sample and work procedure that used by researcher and analysis evaluated by multiple researcher. Graph as a way to represent quantitative data called as data visualization such as bar graph and pie chart. Bar graph is numerical values that represent by variable in a line or rectangle that has a same width while pie chart is a several divide section that represent as a whole.

2.4 Practical Method

In this studies, practical method was used during to run the eco – concrete calculation in Microsoft Excel. The format that set up in this software is linked to each section in calculation. For instance, when the user key – in value for the percentage of waste materials, automatically the ratio of each materials will be change. During set up the specifically format, all of the formula for percentage, ratio, volume of concrete and volume needed of each materials were checking to ensure the calculation do not have error. Testing of this calculation system also was execute in order to ensure this system built function smoothly.

3. Results and Discussion

Result and discussion will explain about observation performance in terms of the comparison mechanical properties between concrete containing different materials such as waste glass, Polyethylene terephthalate, fly ash and rice husk ash and calculation system as an important medium by using Microsoft Excel as tools that must be apply in construction industry. The two main objectives were discussed based on the data finding are to identify the most potential waste materials applied eco-concrete in research by compare the optimal percentage replacement for observe the performance and efficiency in terms effect on mechanical properties of eco – concrete and also build a calculation system for the production of eco - concrete as a facility medium in the construction industry by applying suggestion optimal percentage replacement of waste materials.

3.1 Most potential applied waste materials in Eco – Concrete with comparison of optimal percentage replacement that affected on mechanical properties between concretes containing different waste materials

Inclusion waste materials as partial replacement or additional in concrete is an advancement in construction research to form a sustainable eco - concrete that can be used by industry. A total of 30 journals have reviewed and evaluated the data focusing on four main waste materials that are often used in research, testing and production of products for industry application. Generally, it can be seen as a whole as in **Figure 2** Pie Chart of Total percentage quantity of waste materials applied in eco – concrete around 2000 – 2021 which shows the most applied eco -concrete in research and construction. The

highest waste materials are occupied by waste glass by 30%. Next, followed by 20% of PET and fly ash respectively. The lowest is RHA at 17%. However, there are also eco - concrete that applied a mixture of waste materials which has ranked the lowest below RHA by 13%. Waste material is most widely used because able to produce efficient eco –concrete rather than another material.

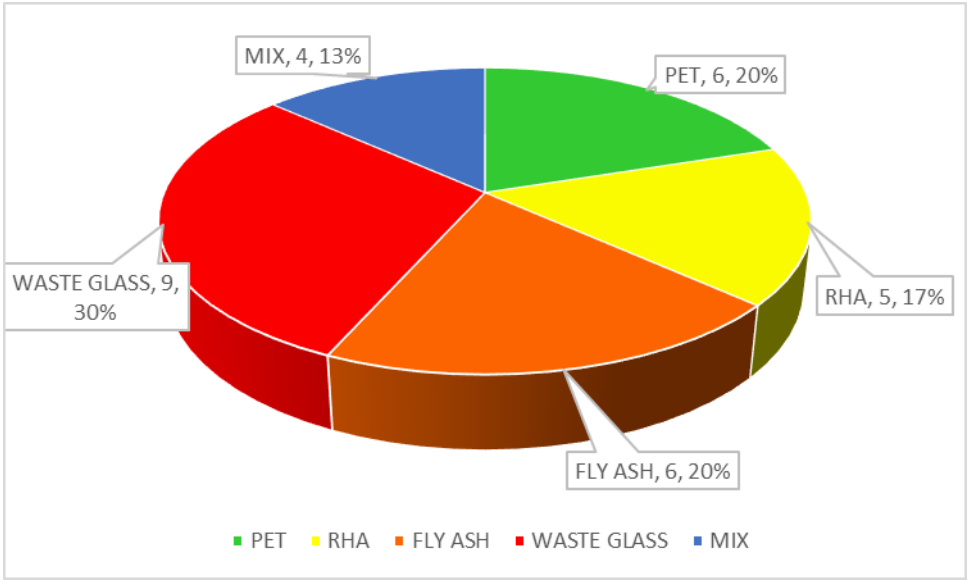

Figure 2: Total Percentage Quantity of Waste Materials Applied in Eco – Concrete Around 2000 - 2021

Based on the results obtained from the journal review, clearly shown in the bar chart of **Figure 3** Quantity of waste materials applied in eco – concrete around 2000 to 2010, the most widely used waste materials in eco - concrete is waste glass. According to [3] optimum replacement of finely milled waste glass (FMWG) is 10% because the strength decreased when over the limit. The optimum amount of FMWG that mention is adequate to react with all liberated lime [Ca(OH)2] generated from the cement hydration process to produce the stable and very dense cementitious compound; calcium silicate hydrate (CSH), which is responsible for enhancing all concrete strengths. All of the excess FMWG over the optimal content functioning only as a filler material and hence, lower strengths will observe due to the content of clinker reduced. Next, recommend by another researcher, the optimal content of waste glass to replace cement in the concrete is 40% [4]. With replace glass powder around 40%, the compressive strength increase after 28 days rather than substitute just 10%. The split tensile strength and flexural strength also increase with 4.4% and 100% respectively. Besides, eco - concrete that contains waste glass only, also found concrete that used waste glass but mixed with other materials. For instance, eco – concrete containing waste glass and fly ash. Studies by [5] suggested 10% from total weight of aggregate as a replacement content for waste glass and fly ash as a activation chemical. Next, research by [6] was compare the durability fine glass powder and fly ash but still has mention the optimum replacement of waste glass is 10%. Refers to the statement that clearly stated optimum replacement level of cement, the percentage replacement is depends on strength and hydration tests. From 2000 to 2010, it can be concluded that the majority of the most widely applied materials in eco – concrete is from materials that related with waste glass.

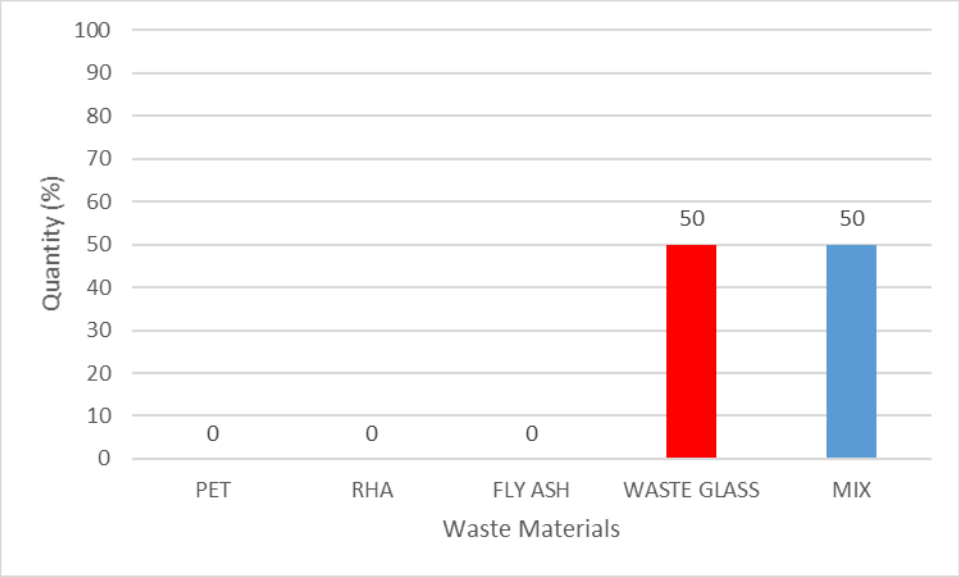

Figure 3: Quantity of waste materials applied in eco – concrete around 2000 to 2010

The application of waste glass into concrete is still one of the most widely used materials based on review, data analysis and observations from 2011 until 2021. According to **Figure 4** Quantity of waste materials applied in eco – concrete around 2011 until 2021, clearly that waste glass is still the highest percentage of material used to produce good quality of eco - concrete. Multiple researcher mentioned the optimal percentage replacement waste glass in concrete is 10% that can give good condition and positive impact during produce eco – concrete. Based on studies by [7] the remaining compressive strength after exposure to heat up to 700°C improved when the addition of 10% glass sand into concrete. As well as enhance remaining compressive strength, positive impact on carbonation resistance at long – term (56 - 91 days) will be observe. Besides, tests on concrete such as compressive strength tests conducted in [8] research explained that the optimal of glass replacement level is 10%. Obviously, can be observed in the testing that 10%, 15% and 20% glass addition lead to mean compressive strengths exceeding the control concrete and 10% cement replacement is one of that show the highest value after 90 days that involve progression of reaction. 25% glass cannot be the optimal of glass replacement level because lead to slightly lower result around 2% compressive strength if compare with control concrete. From the analysis that stated by researcher, concrete has waste glass as potential concrete that can produce compressive strength exceed control concrete strength in long period. Furthermore, other researchers declare statement that multiple studies reviewed mention the optimum replacement level of waste glass that gives maximum strengthen to concrete is 20% such as crushed waste glass as fine aggregate replacement and 10% if used fine glass powder as cement replacement. Contra indication by [9] emphasizing the optimum percentage replacement of waste glass is 25% that lead to enhance compressive strength rather than beyond 50% replacement than lead to produce just low strengthen concrete. Besides that, [10] recommend 20% as a percentage replacement of glass powder that can produce eco – concrete with highest compressive strength rather than applied just 10% or below 20% percentage replacement after 90 days. The compressive strength increase because pozzolanic reaction occurred. In this studies also mention the compressive strength will decrease if used 30% percentage content replacement of glass. However, contra investigation by [11] mention 50% of waste glass cullet as fine aggregate that achieve adequate concrete permeability and strength. Meanwhile, discuss in [12] studies that 16% is optimum replacement for waste glass aggregate. Generally, waste glass is approved to used in produce good eco – concrete that can use by industry.

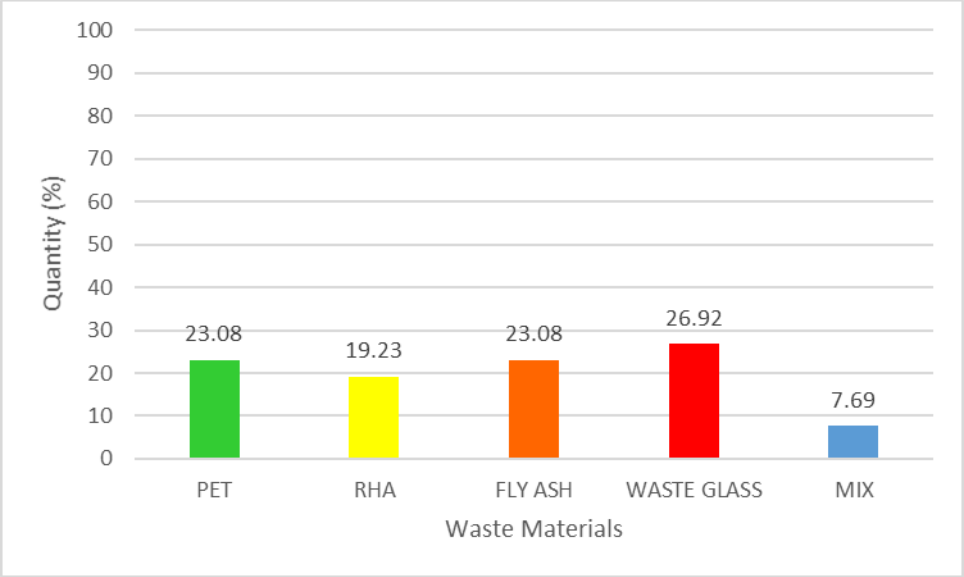

Figure 4: Quantity of waste materials applied in eco – concrete around 2011 until 2021

The second highest materials used in concrete to form eco - concrete were PET and fly ash which each accounted for 23.08%. Two out of six research on PET revealed that the optimal percentage of replacement amount is 2% as a fine aggregate in concrete. Based on [13] and [14] research, the compressive and split tensile strength increase rather than 4% and 6% replacement that can lead to decreased result. As same to another material that mention by multiple studies, 10% as an optimum substitute level of PET in concrete. Nevertheless, the compressive strength, tensile strength and also flexural strength still has declined slightly but not decrease significantly if compare with replace up to 10% above of PET [15]. Apart from that, according to one study, the ideal amount of PET added in concrete is 0.18% - 0.30%, which has a positive influence on energy absorption and toughness properties of the concrete against flexural load [16]. Although most of suggestion percentage replacement already lower but still has another studies applied just 0.75% as an optimum percentage replacement of PET in concrete. 0.75% as optimum percentage replacement of PET can produce greater resilient modulus and also affected to tensile strength [17]. Besides, another review stated 20% as percentage replacement of PET that shows greater workability but still the compressive strength is lower than conventional concrete. From the explanation about performance PET in eco – concrete, PET is one of recommended material that can be used during produce strong concrete because give benefit not only in terms of mechanical properties but also enhance the quality of environment by recycle the things that have PET.

[18] used 10% as replacement of cement by fly ash. In that studies, the result in the concrete testing explain the compressive strength of concrete containing fly ash is more higher rather than reference mixture that does not have fly ash as the additional or replacement content at 100 to 130 days. The situation occurs because fineness additive and additional materials that lead to pozzolanic reaction, indirectly give effect to pore structure and also reduce the total of porosity. Research by [19] indicate 10% from weight of cement as percentage substitute fly ash class F to cement that to build sufficient bond strength between fiber and cementitious properties. Besides that, in investigation by [20] the 10% of fly ash replacement also clearly illustrate highest value in compressive strength, split tensile strength and flexural strength test. The Saudi fly ash content very influence in resistance to abrasion that will give effect to the hardened strength of concrete. In addition, the flexural strength can be enhanced but need to mix with 0.08% structural fiber. Indirectly, the compressive and tensile strength also increase but if the content of structural fiber over 0.08%, then the contradict effect on concrete occur. The

optimal replacement fly ash level mentioned by [21] is 40%. The compressive strength of concrete containing fly ash just showed improvement between 28 untill 180 days. The reason to the situation occur because reaction between aluminosil particles and free portlandite to form cement compound is very slow. Different statement from [22] that 25% is optimal percentage replacement for fly ash can lead to the greater compressive strength of 80 MPa, highest resistivity but the percentage of fly ash content cannot be more than 25% because lead to the strength of the mortar specimen decrease. In addition, can lead to other disadvantages where content is a factor that affects pozzolanic activity. Different recommendation from [23] stated 35% of cement as percentage replacement of Class C fly ash that can built optimum strength in concrete. As a result, shows the highest value of compressive strength at 28-ages. Fly ash can be material that replacing in eco – concrete because shows good performance that influence by pozzolanic characteristics factor.

After that, the second lowest of the most applied material in eco – concrete during that time is eco – concrete that used rice husk ash. [24] declare 20% as a suitable percentage of content in concrete. However, the increased strength of concrete containing RHA lower than normal concrete at early age but shows strength development after 270 days as presented in **Figure 5**. The partial replacement of cement by 20% RHA also shows tensile strength as including in Figure. The tensile strength of concrete containing RHA still lower if compare with normal concrete during 90 days and below ages but more greater rather than conventional concrete at later ages. In contrast, revealed by [25] the optimum content of replacement level for Ordinary Portland Cement (OPC) is between 10% to 30% that enhance the compressive strength of concrete. However, if the content replacement is over 30%, the strength of concrete will be reduced. Percentage replacement of RHA is one of factor influence to produce good concrete. For instance, the right amount of RHA can reduce permeability, control effect of alkali – silica reactivity, improve workability and most importantly can enhance the consistency blended mixture of OPC and RHA. Corrosion resistance and strength of concrete also will be more effective than conventional concrete if applied the suitable percentage amount replacement of RHA. Suggested by [26] the optimum replacement amount for WRHA is 25%. The effect by replace 25% WRHA is make bulk density decrease without give impact to compressive strength. Nevertheless, different investigation with [27] that stated the optimum content of percentage replacement RHA is up to 10% can build strength development and produce the durable concrete specimen. Another review mention 20% as percentage replacement of RHA that give improvement in compressive strength and, corrosion potential can be decrease [28]. Replace RHA in concrete shows the positive effect on concrete but still have side of bad impact.

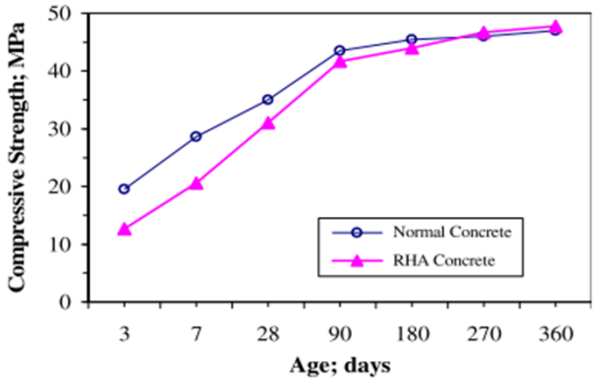

Figure 5: Development of compressive strength with age [24]

Although multiple studies show that a type of waste material is able to produce strong eco - concrete but there are minor studies that investigate the mixing of waste material with other additional materials. In this studies, two out of 26 studies from 2011 until 2021 applied mix of materials to produce eco –

concrete. For example, [29] recommend the mixture must 0.25% PET, 35% Fly ash and 5% Nano Silica (NS) into concrete that generate 49.6% compressive strength and 30% flexural strength at 400 °C but both of the characteristic will decrease if temperature increase. Basically, presence of Fly ash and NS will influence in refinement of pores that can enhance the mechanical properties of concrete. However, if NS not exists in substitute materials, mechanical properties will affect and shows bad impact of concrete. Besides, [30] mix waste glass and silica fume to produce good material replacement of cement. Substitute 15% from cement to silica fume lead to result of porosity of concrete decrease and enhance hydration reaction rate. While replacing 10% with glass powder can curb the strength properties of concrete from adverse effect but the glass powder that used should in 0 to 75 μm range. With applying 15% silica fume and 10% waste glass, the mechanical properties such as compressive strength, tensile strength and also flexural strength can be enhanced. Mix of material is one of good suggestion material for another researcher that want to produce good concrete and also built sustainable environment.

The most waste materials applied in eco – concrete since 2003 until 2021 is waste glass or glass powder. The factor that encourage multiple researcher to use waste glass are performance of the concrete that can view and observe from mechanical properties. Majority of studies used below 20% as an optimum percentage replacement of waste glass or glass powder to improve development strengthen of concrete. With applying waste glass in eco – concrete, the highest value of compressive, tensile and flexural strength can be achieved. In addition, numerous research declare that waste glass also can give good result in terms of mechanical properties and strengthen that similar with conventional concrete. Therefore, waste glass as material in eco – concrete is recommended because give more benefit that not only improve mechanical properties but also can reduce cost especially on landfill, produce more economical building material, protect environment and others.

3.2 Eco – Concrete Calculation System

Based on the critical review, simple calculations can be makes to calculate basic ratio and how much material is needed to make a concrete sample based on the content of material such as PET, Rice Husk, Fly Ash and Waste Glass. The calculation is use by using ratio such as on the right side it has value of waste per total that in percentage and the left side the ratio we need per the total ratio given. User just add the input for any content of material that in percentage and also the volume of square shape sample concrete. After that, excel will calculate the amount needed in kilogram cube (kg^3). The significance of this eco – concrete calculation system is facilitate the production of eco - concrete for use in the construction industry where eco - concrete producers can save time during determining the appropriate ratio and volume to make eco - concrete. Besides, this calculation system can be introduced especially to internship student of Civil Engineering as potential innovation that improve process during produce eco – concrete.

3.2.1 Step of Eco – Concrete calculation system

i. For this the user can input the percentage they wanted for waste material. at first each material that is sand, cement and aggregate has a fixed value that is 18.2%, 27.3% and 54.5% respectively. If the input for waste material is 20% it will subtract the amount of aggregate only to make the total percentage is 100%. As present in Eq.1 and Eq.2 the formula that used in this section.

Percentage component in eco - concrete				
sand	cement	aggregate	waste material	total
18.2	27.3	34.5	20	100

$$New\ percentage\ of\ aggregate = 54.5 - waste\ material \quad \textbf{Eq. 1}$$

$$Total\ of\ precentage = \Sigma\ sum\ of\ percentage\ of\ material \quad \textbf{Eq. 2}$$

ii. For second step is it will calculate ratio needed for each waste material. The formula use as in Eq.3:

Ratio component in eco concrete				
cement	sand	aggregate	waste material	total
1.5	1.0	1.9	1.1	5.5

$$Ratio\ X = \frac{Percentage\ of\ material}{\Sigma Percentage}\ \text{x}\ \Sigma\text{Ratio} \quad \textbf{Eq. 3}$$

iii. This is how to calculate concrete dimension in cm^3. Formula present as Eq.4 used in this section.

Concrete dimension			
width (cm)	length(cm)	height(cm)	total (cm^3)
10	10	10	1000

$$Volume\ of\ concrete = Length\ \text{x}\ Wide\ \text{x}\ Height \quad \textbf{Eq. 4}$$

iv. Lastly, for this table the user can calculate the volume needed for each material. The formula use shown as in Eq.5.

Volume for each component that needed in eco - concrete (cm^3)			
cement	sand	aggregate	waste material
273.0	182.0	345.0	200.0

$$Volume\ X = \frac{ratio\ of\ material}{\Sigma ratio}\ \text{x}\ volume\ of\ concrete \quad \textbf{Eq. 5}$$

X = material

4. Conclusion

The most used waste material in eco concrete according to the most studied in recent years is waste glass. 30% of the research paper studied were mostly is waste glass and follow by fly ash 20%, PET 20%, rice husk 17% and the rest is mix waste material. One of the improved eco concrete is using only 10% of waste glass can maximum achieved compressive strength and can withstand 700°C. For the other waste material, its effects in their league such as the best measure of PET included cement is 0.18% - 0.30%, which affects energy retention and sturdiness properties of the substantial against flexural load. 20% as percentage replacement of rice husk that give improvement in compressive strength and, corrosion potential can be decrease. Lastly, majority of research suggest 10% - 25% as fly ash replacement content that improve the quality of concrete in terms of mechanical properties. As the study is restricted to reviewing, therefore it only can be proved by analysing article journals and research paper in this studies which is more advisable to produce a sample in the laboratory in order to maximize the efficiency of waste material in eco – concrete.

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