A SYSTEMATIC LITERATURE REVIEW ON MAGNESIUM OXIDE AS EXPANSIVE AGENT IN SELF HEALING CONCRETE

LOW PHAK HO

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IN SELF HEALING CONCRETE

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LOW PHAK HO

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Name of Student: LOW PHAK HO

I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

Signature:

Date : 2/8/2021

Endorsed by:

Badorul hisham

(Signature of Supervisor)

Name of Supervisor: Professor Ir. Dr.

Badorul Hisham Abu Bakar

Date: 3hb.Ogos 2021

Approved by:

(Signature of Examiner)

Name of Examiner:

Assoc. Prof. Ts. Dr. Mohd Rosli Mohd Hasan
School of Civil Engineering
Engineering Campus, Universiti Sains Malaysia
14300 Nibong Tebal, Penang, Malaysia
Tel: +604-5996288 Fax: +604-5996906

Date: 3/8/2021

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ABSTRAK

Artikel ini merupakan tinjauan literatur sistematik mengenai magnesium oksida (MgO) dalam konkrit penyembuhan diri. Objektif kajian ini adalah untuk meneliti keberkesanan MgO sebagai agen konkrit penyembuhan diri, mengenalpasti dan menilai penemuan urutan dalam penggunaan MgO dalam konkrit penyembuhan diri dan untuk mengenal pasti jurang pengetahuan dalam penerapan MgO sebagai agen pengembangan dalam konkrit penyembuhan diri. Untuk makluman, konkrit penyembuhan diri dapat menyembuhkan retakan secara automatik tanpa memerlukan mekanisme asing tambahan demi memulihkan kekuatan dan ketahanan. Namun, sifat pengembangan MgO dalam konkrit terus membantu mengisi keretakan. Oleh itu, 17 artikel dimasukkan dalam tinjauan ini dari pangkalan data Scopus. Strategi pencarian sistematik digunakan untuk menyaring artikel yang tidak relevan dan penilaian kualiti artikel juga digunakan untuk menghindari penerbitan kualiti metodologi yang buruk. Dalam tinjauan ini, sistem kalsinasi, kereaktifan MgO dan nano-MgO telah dibincangkan. Hasil kajian menunjukkan bahawa suhu kalsinasi dan masa tahan akan mempengaruhi kereaktifan MgO. Kemudian, hubungan antara MgO dan mineral lain seperti SCM atau bahan tambahan penyembuhan telah diselidiki dan hasilnya menunjukkan gabungan mineral dan MgO mempunyai prestasi yang baik daripada MgO individu. Di samping itu, kaedah aplikasi dan persekitaran AMD bagi konkrit kandungan MgO telah dikaji. Penggabungan MgO dalam konkrit dalam kebanyakan persekitaran secara amnya menurunkan kekuatan dan pengecutan tetapi meningkatkan pemulihan kekuatan dan ketahanan beban seperti pengurangan kawasan retakan, juga rendahkan kebolehtelapan gas dan penyerapan air. Selanjutnya, penyebaran agen penyembuhan dan ciri pelet adalah masalah utama yang harus dimanipulasi agar tidak mempengaruhi sifat konkrit serta menjaga sistem penyembuhan diri.

ABSTRACT

This dissertation presents a systematic literature review about the magnesium oxide (MgO) in the self-healing concrete. The objectives of this review is to appraise the effectiveness of MgO as an agent for self-healing concrete. Besides, this review also identify and evaluate the sequence findings in the application of MgO in self-healing concrete and identify the gap of knowledge in the application of MgO as an expansive agent for self-healing concrete. For the information, self-healing concrete can heal the crack automatically without any external intervention to regain strength and durability. Yet, the expansion behaviour of MgO in the concrete helped to fill the crack. Therefore, there were 17 articles had been identified in this review from the Scopus database. Systematic searching strategies had been used to screen out the irrelevant articles and the article quality assessment also being used to avoid the publications of poor methodological quality. In this review, the calcination system, reactivity of MgO and nano-MgO were discussed. Results showed that the calcination temperature and holding time will directly affect the reactivity of MgO. Then, relationship between MgO and the other minerals such SCM or curing additive were investigated, and the results showed that the combination of mineral and MgO showed better performance than the individual MgO. In addition, the application method and AMD environment for concrete with MgO were studied. The MgO incorporation in concrete in most environment condition generally decreases the strength and shrinkage but improved the load recovery and durability indicator such as higher crack area reduction, low gas permeability and water absorption. Furthermore, the diffusion of healing agent and characteristic of pellet were the main issue to be manipulated in order not to affect the concrete's properties as well as maintain the self-healing behaviour.

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LIST OF ABBREVIATIONS

AMD	Acid Mine Drainage
CBA	Coal Bottom Ash Particles
CON	Control
ECC	Engineered Cementitious Composite
HPC	High Performance Concrete
PVA	Polyvinyl Alcohol
SAP	Superabsorbent Polymer
SCM	Supplementary Cementitious Material
SHCC	Strain-Hardening Cementitious Composites
TGA	Thermogravimetric Analysis
UEA	United Expansive Agent
UPV	Ultrasonic Pulse Velocity
USM	Universiti Sains Malaysia

CHAPTER 1

INTRODUCTION

1.1 Background

Concrete is a construction material composed of cement, water, fine aggregate and coarse aggregate. Concrete is very important in the construction field as it was reported 5.30 billion m^3 of concrete used globally per year (Sherir et al., 2016). When the cement is mixed with aggregate and water, the cement and water will undergo a chemical reaction called hydration, then the mixture will form a hard matrix that binds the materials together into the desired shape. Besides, properties of the concrete provide benefits as construction material such as high compressive strength, resistance to water and low cost. Other than the normally used materials mentioned above, concrete also can mix with reinforced steel or other equivalent material such as fiber to achieve the desired strength or other purposes. Therefore, it had become a significant material in building construction such as foundation, column, beam, slab, or other bearing elements. However, concrete also is a brittle material will have its limitation in certain applications due to its low tensile strength and ductility (Sherir et al., 2016). Therefore, concrete will crack when under tension, shrinkage, fatigue loading or action of environmental condition. Those cracks will affect the concrete's toughness, increase permeability which then leads to a reduction of integrity and its life span (Qureshi and Al-Tabbaa, 2020). As a result, there will be an increase in the cost of renovate or maintenance activities from year to year.

To prevent and limit the crack's effect to concrete, a specially modified composition of concrete – self-healing concrete had been invented. Self-healing concrete can play a role to repair or close the crack automatically without any external intervention to regain strength and durability based on mechanical properties. In self-

healing concrete, there are two types of principles to heal itself which are autogenic (autogenous) and autonomic (autonomous). For the autogenic system, self-healing concrete has its intrinsic material-healing property from the generic materials present. One of the principal causes of autogenic healing is the rehydration of unhydrated cement in the concrete. However, the width of crack being healed is limited and only effective at the early age of concrete (Wu et al., 2012). As a result, adding fibre to restrict crack opening or adding expansive agents and optimal supplementary cementitious materials (SCMs) is another method to heal the crack and improve autogenic healing efficiency. In contrast, the properties of healing from the materials that are not traditionally used in concrete are termed autonomic self-healing. This process involved the encapsulation or continuous vascular network to release the healing agent to the cracked concrete. Sometimes, it may also use bacteria as a medium to precipitate calcite through biological metabolism in concrete (Qureshi and Al-Tabbaa, 2020).

In self-healing concrete, MgO-based concrete was developed by a Chinese dam engineer and applied predominantly in the construction of the dam in China (Jiang, 2005). As an expansive agent, the presence of MgO in the concrete will expand itself when react with the surrounding water and this action will fill the crack. A substitution of cement content up to 5-7.5% will result in optimum enhancement of autogenous self-healing in the cement mix (Qureshi and Al-Tabbaa, 2020). Besides, MgO used in the concrete may also increase the mechanical strength of the concrete at the early age (about 14days) because the reaction of MgO with water produces internal stress which will balance the thermal shrinkage stress, thus results in the strength development (Qureshi et al., 2018). However, the over substitution of MgO in the cement content will lead to disruptive expansions in concrete at the later age. Moreover, a higher

replacement percentage of cement content in concrete will also induce less hydration of cement then reduce the strength of the concrete. In the meantime, the grade of MgO adopted will also have a different effect on the concrete's performance due to its different chemical and physical properties (Qureshi and Al-Tabbaa, 2016).

To maximize the efficiency of MgO in self-healing concrete, the method to apply the MgO during the mixing stage is important. MgO can be used with other materials and added to the concrete mix or capsuled inside the microcapsule before the casting. The methods to apply the MgO have their consideration due to the concrete grade, mix proportion, ambient condition and etc. Then, each method applied to MgO will have its pros and cons, therefore decisions must be made carefully so that the mechanical properties of the concrete will not be affected. Since repair and reconstruction of structure is an extensive investment, therefore using self-healing concrete also will be an effective approach to reduce the maintenance cost and longer the service life (Dybel and Kucharska, 2019).

1.2 Review Questions

1) What is the best form of MgO to be used as an expanding agent in self-healing concrete?
2) When and how the sequence findings of MgO application in self-healing concrete?
3) What is the next journey or direction of research in this field?

1.3 Objectives of the Systematic Review

1) To review the effectiveness of MgO as an agent for self-healing concrete.

2) To identify and evaluate the sequence findings in the application of MgO in self-healing concrete.

3) To identify the gap of knowledge in the application of MgO as an expansive agent for self-healing concrete.

1.4 Problem Statement

In Malaysia's construction industry, concrete structures are the main type of building facade due to their low construction cost, durability, and availability of raw materials. Meanwhile, the crack in the concrete will affect the durability and integrity of the structure. However, people are not serious about taking care at the early age of concrete maturity, they are only aware of the crack developed after the completion of the work. Therefore, a new generation of concrete - self-healing concrete need to be introduced. MgO as an expansive agent used in self-healing concrete can help to heal or close the crack by itself. Therefore, this study is focusing on the effectiveness of MgO as an agent, the sequence finding and the gap of knowledge in the application of MgO in self-healing concrete. Therefore, this study would be able to provide a better understanding of the effect of MgO on the crack in the concrete.

1.5 Significance of the Systematic Review

The overall aim of this study is to understand the effect of MgO as an expansive agent applied in self-healing concrete. Then, this study can help to determine the grade and percentage of MgO used in the concrete mix to reach the optimum self-healing behaviour in the concrete. Lastly, the information of the literature review about MgO in self-healing concrete can be used as guideline and reference in designing the concrete mixtures.

1.6 Organization of the Report

This study consists of 5 main chapters, each chapter discusses a different topic related to the title. Through the sequence of the chapter, the reader can understand the thesis from shallow to deep. The following is the summary of these chapters in this dissertation from chapter 1 to chapter 5.

The first chapter provides an outline of the study. The background of the study, review question, objective, problem statement, and significance of the study will be discussed in this chapter.

Chapter 2 discusses the methodology part of the study. It will discuss the planning process of the systematic literature review before conducting this review. In this chapter, it will mention the protocol, review question, searching strategies, quality assessment, data extraction, data synthesis and the reporting of the review.

For the deeper explanation of data extraction and data synthesis, they are defined in Chapter 3. This chapter addresses some overview and the method used when conducting extraction and synthesis. These processes are crucial as they are the last process before making the summary or conclusion for the review.

Chapter 4 shows the discussion and analysis of the information obtained from the research article studied. Information obtained from the article will be arranged to answer the review question in this review. Besides, the divergences of the articles will be discussed and also the gap of knowledge of those articles.

Lastly, chapter 5 presents the conclusion of the study after reviewing the articles and interpretation of the gap of knowledge found in this study. Recommendation for future study is also stated in this chapter.

CHAPTER 2

SYSTEMATIC LITERATURE REVIEW: A METHODOLOGY

2.1 Introduction

The literature review is a discussion or summary of the published information in a subject area. It not only can be a part of the research work or dissertation to give a different view angle to the work, but it may also be a stand-alone review in a subject area (Jesson et al., 2011). The literature review can be said as a simple summary of the sources, but it consists of the summary and synthesis at the same time. A summary is to extract the important information from the sources while the synthesis is to reorganize and reshuffle the information. Through the synthesis of the information, a new opinion or argument can be inspired by old materials or combined new with old materials (Center, 2021). Besides, through the literature review, the researcher who already an expert in his field or able to interpret the existed knowledge can point out the contradiction and the gap of knowledge from the reviewed information. By this, a literature review can give convenience to the reader for them to access the most relevant and reliable information.

The literature review usually can be grouped into two categories which are traditional and systematic review. Traditional review is aimed to describe and discuss the topic where the author wants to. The author who has strong confidence in his view will select the paper which supports his point, left out all the one that doesn't support his point. Besides, the authors who are expert in his field, they usually present the overview in his thesis or paper with no clear methodological approach. Failure to apply the scientific principles in the review also will not produce an unbiased and reliable reviewing evidence, thus having an inaccurate conclusion. (Petticrew and Roberts, 2006).

The systematic literature review is a contrast with the traditional review. It requires reviewing a large amount of the information to determine the answer to the questions about what is works and what doesn't. The relevant information from the research article will be identified, selected and synthesized to answer the review question. In the systematic review, there has a strict and well-defined method for conducting the review, unlike the traditional review. It has a clearly stated aim, review question, searching method, stating inclusion and exclusion criteria, etc. to produce a qualitative review paper (Jesson et al., 2011). Because of reviewing a large amount of the paper or article based on the review question, the contradiction and gap of knowledge can be easily known as well as clarify where the research is needed to further undergo in future (Jesson et al., 2011).

2.2 Planning of SLR

This systematic review is to appraise magnesium oxide as an expansive agent in self-healing concrete. Some basic understanding or background about the title is required because it can help to form a brief overview on how to develop the sections such as objective, review question, protocol and methodologies (Bettany-Saltikov, 2012). Yet, a systematic review has its strict method to conduct the review, a clear review protocol must be developed before the starting of the review. In this review protocol, three stages can be summarized from the starting of the review to the end of the review, which is the planning stage, conducting stage and reporting stage. Through those stages, it specifies the procedures for each stage so that the review can carry on smoothly and minimize the author bias when presenting the discussion.

2.2.1 Review Protocol

Before conducting the systematic literature review, a clear protocol is needed as it can be a guide to carry out the review. The preparation of a protocol is an integral component of the systematic review process. It assures that a systematic review is carefully prepared and that what is scheduled is reported before the review begins, fostering transparent review team behaviour, reliability, scientific credibility, and transparency of the final completed review (Moher et al., 2015). With the protocol, it will be easy to specify the objectives, review questions and purpose of the project because it is an explicit statement and explanation of the steps that should be taken (Jesson et al., 2011).

In this review protocol, the PRISMA-P (Preferred reporting items for systematic review and meta-analysis protocols) checklist is adopted for the preparation of the protocols. PRISMA-P aims to improve the quality and consistency of systematic review protocols, like the other reporting guidelines giving similar impart to review such as Cochrane and Campbell. PRISMA-P is a checklist that lets scholars formulate protocols for proposed systematic reviews and meta-analyses by providing them with a minimum list of things to use in the protocol. Before embarking on a review, it provides the rationale for the review as well as the pre-planned methodological and analytic approach (Moher et al., 2015).

PRISMA-P 2015 checklist contains 17 numbered item and are categorized into three main sections which are administrative information, introduction and methods. However, this review only adopts some items that list in PRISMA-P (Table 2.1Table 2.1: Selected PRISMA-P items when conducting the review.) and the protocol is separated into three stages which are the planning stage, conducting stage and reporting stage (Figure 2.1).

Table 2.1: Selected PRISMA-P items when conducting the review.

Item no.	Item in PRISMA-P	Detail
6	Rationale	Describe the rationale for the review in the context of what is already known
7	Objectives	Provide an explicit statement of the question(s) the review will address with reference to participants, interventions, comparators, and outcomes (PICO)
8	Eligibility criteria	Specify the study characteristics (such as PICO, study design, setting, time frame) and report characteristics (such as years considered, language, publication status) to be used as criteria for eligibility for the review
9	Information sources	Describe all intended information sources (such as electronic databases, contact with study authors, trial registers or other grey literature sources) with planned dates of coverage
10	Search strategy	Present draft of search strategy to be used for at least one electronic database, including planned limits, such that it could be repeated
11a	Data management	Describe the mechanism(s) that will be used to manage records and data throughout the review
11b	Selection process	State the process that will be used for selecting studies (such as two independent reviewers) through each phase of the review (that is, screening, eligibility and inclusion in meta-analysis)
11c	Data collection process	Describe planned method of extracting data from reports (such as piloting forms, done independently, in duplicate), any processes for obtaining and confirming data from investigators
12	Data items	List and define all variables for which data will be sought (such as PICO items, funding sources), any pre-planned data assumptions and simplifications
13	Outcomes and prioritization	List and define all outcomes for which data will be sought, including prioritization of main and additional outcomes, with rationale
14	Risk of bias in individual studies	Describe anticipated methods for assessing risk of bias of individual studies, including whether this will be done at the outcome or study level, or both; state how this information will be used in data synthesis
15d	Data synthesis	If quantitative synthesis is not appropriate, describe the type of summary planned
16	Meta-bias(es)	Specify any planned assessment of meta-bias(es) (such as publication bias across studies, selective reporting within studies)
17	Confidence in cumulative evidence	Describe how the strength of the body of evidence will be assessed (such as GRADE)

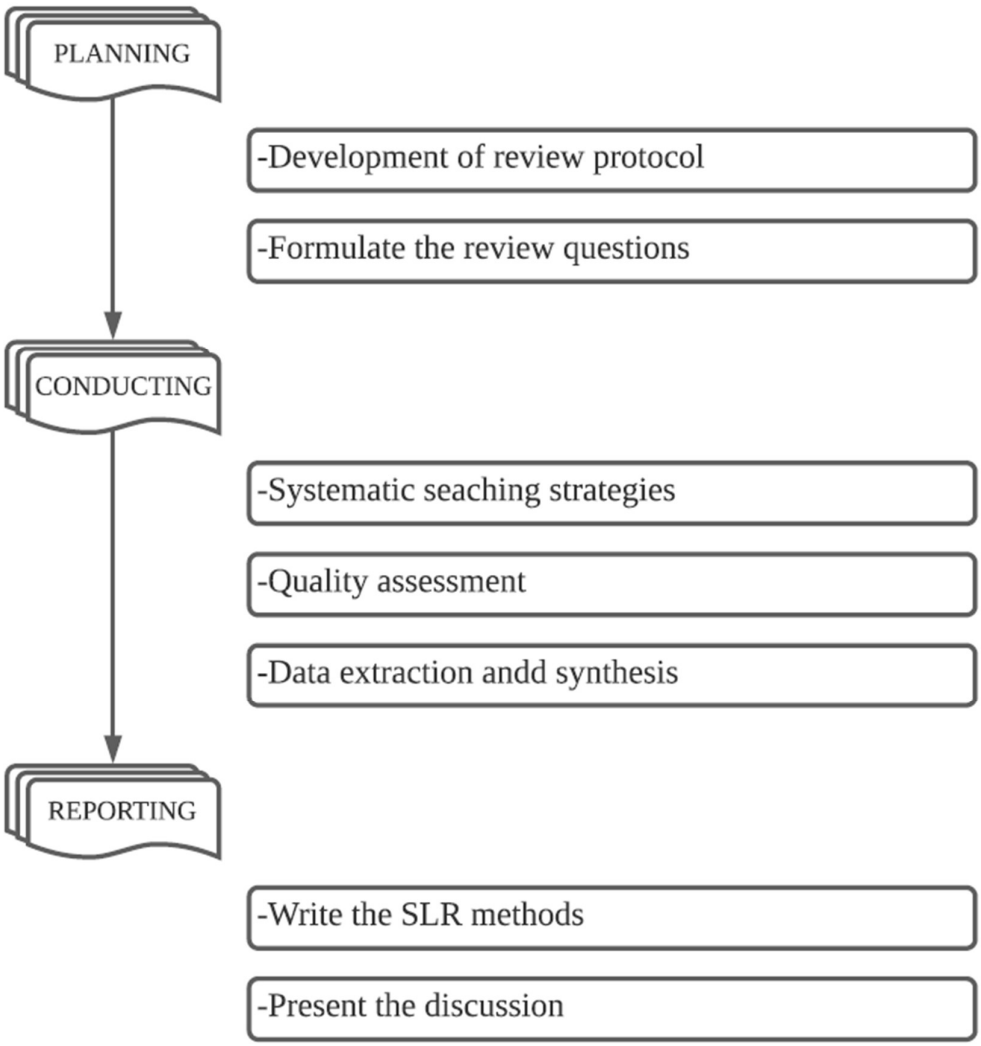

Figure 2.1: Flow chart of the review protocol.

In the planning stage, once the title of the study has been determined, a review protocol must be formulated. Then, the objectives of the review will be specified to provide a clear statement question or review question addressed concerning participants, interventions, comparators and outcomes (PICO). Further discussion of the review question is in section 2.2.2.

In conducting stage, it is more focused on the searching and processing of the research article. Systematic searching strategies are used to finding the related article from the database by using the main term from topic and objective. Then, the filtering process for the articles is carried out to exclude the irrelevant and duplicated article,

left only the vital article. After the searching of the article from the database, a quality assessment for the selected article will be carried out. Quality assessment is one of the article appraisals to show how much the sensitivity and accuracy of an article can be met with the review question or objective (CRD, 2009). Therefore, it gives less bias and more reliable to the review. For the data extraction part, it is the procedure for data extraction from each article such as the author, the aim of the study and the result of the study. Meanwhile, the data synthesis part is responsible for synchronizing all the articles to find the answer to the review question. Since this systematic literature review is qualitative, the combined result will be categorized under major themes or subthemes (Bettany-Saltikov, 2012). Therefore, the information extracted from each article will be present in a table so that the contradiction and similarity of each article can be easily shown and reviewed.

In reporting stage, it is the process to summarize, synthesize, and present the answer to the review questions. In this study, the report will be reviewed under the themes or categories which are thematic analysis. A thematic analysis of literature is a technique of evaluating qualitative data that closely examines the data to define similar themes – concepts, thoughts, and trends of context that appear frequently (Caulfield, 2019). Since there will have a table of thematic synthesized information from each article, there will be easy for us to answer the review question that is set at the planning stage and can interpret the gap of knowledge among the articles. Apart from this, the recommendation can be done for future researchers about the topic or field to improve their future work.

2.2.2 Formulation of Review Questions

A systematic review should set the specific questions, the answer to the question should include useful knowledge to help direct decision-making. In the protocol, these should be specified explicitly and specifically. Questions may be highly precise or very general; but, if broad, it might be easier to break these down into a set of similar more specific questions (CRD, 2009). In other words, a well-formulated question can promote many aspects of the review process, such as deciding eligibility requirements, searching for articles, gathering data from the included article, and presenting the result.

The objectives of this systematic review are considered when formulating the review question. To match the review questions with the objective, one review question will be applied to each objective, with a total of three review questions in this systemic review. Therefore, a question format – PICO is used to structure a review question to promote a search. In term of PICO, "P" stands for patient, "I" stand for intervention, "C" stands for comparison and "O" is stand for Outcome. However, the PICO framework is usually used to develop the clinical questions for quantitative literature review, then, a modified framework based on PICO is used which is PICo (LibGuides, 2021).

As said above, PICo is the modification of PICO, which is suitable used for qualitative systematic review and each letter's meaning in PICo is different compared to PICO. In PICo, "P" stands for population, "I" stand for interest and "Co" stands for context. A comparison between PICO and PICo is then summarized in Table 2.2 (LibGuides, 2021). For the review question for each objective based on PICo framework, they are shown in Table 2.3.

Table 2.2: Description of the PICO and PICo.

PICO	Meaning	PICo	Meaning
P – population	What are the characteristics of the patient or problem?	P - population	What is the Problem, condition or disease you are interested in?
I - intervention	What do you want to do with this patient	I – interest	What are the phenomena of interest?
C – comparison	What is the alternative to the intervention	Co - context	What is the setting or distinct characteristics?
O - outcome	What are the relevant outcomes		

Table 2.3: Relationship of the review question with the PICo framework.

Objective 1 (RO1)	To review the effectiveness of MgO as an agent for self-healing concrete	
Review question (RQ1)	What is the best form of MgO to be used as an expanding agent in self-healing concrete?	
P	I	Co
Expanding agent	Best form of MgO	Self-healing concrete

Objective 2 (RO2)	To identify and evaluate the sequence findings in the application of MgO in self-healing concrete.	
Review question 2 (RQ2)	When and how the sequence findings of MgO application in self-healing concrete?	
P	I	Co
MgO application	Sequence findings	Self-healing concrete

Objective 3 (RO3)	To identify the gap of knowledge in the application of MgO as an expansive agent for self-healing concrete.	
Review question 3 (RQ3)	What is next journey or direction of research in this field?	
P	I	Co
Research (application of MgO in self-healing concrete)	Next journey or direction	Review (systematic literature review)

2.3 Conducting the SLR

A systematic review is a review of the literature that is intended to identify, evaluate, and synthesize the best available information relating to a research question to provide informative and evidence-based answers (Boland et al., 2017). When conducting the systematic review, it is important to obtain as many as possible studies that are related to the objectives or the review questions. A searching strategy will be applied by defining the synonym for the objective and the review question to widen the searching and then filtering for the eligibility article is done. Once finishing the filtering, the quality assessment for the article included will be done to examine the confidence of review findings for extra evaluation on the methodological quality of the research (Seo and Kim, 2012). Then, data extraction and synthesis for the article will be carried out to obtain and process the necessary information about the study characteristics and findings from the studies (CRD, 2009).

2.3.1 Systematic Searching Strategies

In this systematic review, systematic searching strategies aim to identify potential articles from the electronic database and then filtering the unwanted articles.

There are three stages of conducting the strategized searching, which is identification, screening and eligibility stage.

During the identification stage, the electronic database used in this review is Scopus, which is owned by Elsevier and is the largest abstract and citation database of peer-reviewed literature. In this review, there are five searching statements based on the topic, objectives and review questions. To achieve the sensitivity and specificity in searching, topic, objectives and review questions are used by differentiating the keyword or main term from the sentences and then enriching them for the synonym, related and variation terms so that can retrieve a high portion of the relevant article and less portion of the irreverent article (Petticrew and Roberts, 2006) (see Table 2.4). Then, the Boolean operator is used to connect keywords and the enriched keyword to form a searching string when performing the searching in Scopus. Boolean "OR" is used for synonym, related and variation terms while Boolean "AND" is used for linking the main term. After all the keywords and the enriched term is confirmed, the searching string is applying in Scopus to perform searching. For the information, the searching strings for each statement can be referred to Table 2.5.

In the screening stage, it is to filter out the irrelevant articles which are from the identification stage based on the inclusion and exclusion criteria (see Table 2.6) and has two phases. The first phase of the screening stage for the articles is limited to the timeline publication of the latest 5 years (2016-2020), article type document, final publication document and English. Then, the second phase involves sifting through the title and the abstract of the remaining articles, if necessary, reading through the full text of the articles to make sure the article can answer the review questions (Bettany-Saltikov, 2012). Since there are 5 searching statements in this review, therefore the screening stage is done for each searching statement. Throughout both phases, it is

helpful to establish an acceptable research paper selection form to standardize the papers that match the predetermined criteria.

Once the screening stage is completed, the eligibility stage will be carried out. In this stage, all the searching articles based on each searching statement are checking for duplication. The duplicated articles will be excluded, and the remaining articles are the ones that need to be reviewed. To simplify the process, all the articles are input and arranged in Endnote to eliminate the duplicated articles easily.

Overall, the number of articles in each stage (identification, screening, eligibility) is recorded down (see Plate 2.1). These searching strategies can ensure the review is transparent and neutral without bias on one side. As a result, these will improve the validity or truthfulness of the results in the review.

Table 2.4: Searching statement with the main term and the enriched keyword in identification stage.

Searching statement	Main keywords	Enriched keywords
Topic: A systematic literature review on MgO as expansive agent in self-healing concrete	• MgO • expansive • agent • self-healing concrete	• Magnesium Oxide • expanding • material, admixture • self-repairing concrete
RO1: To review the effectiveness of MgO as an agent for self-healing concrete.	• effectiveness • MgO • agent • self-healing concrete	• efficiency, efficacy, capability, performance, strength • Magnesium Oxide • material, admixture • self-repairing concrete
RQ1: What is the best form of MgO to be used as an expanding agent in self-healing concrete?	• best • form • MgO • expansive • agent • self-healing concrete.	• top, premier, optimum, foremost • type • Magnesium Oxide • expanding • material, admixture • self-repairing concrete
RO2: To identify and evaluate the sequence findings in the application of MgO in self-healing concrete.	• application • MgO • self-healing concrete	• adoption, implantation, using • Magnesium Oxide • self-repairing concrete
RQ2: When and how the sequence findings of MgO application in self-healing concrete?	• MgO • application • self-healing concrete	• Magnesium Oxide • adoption, implantation, using • self-repairing concrete
RO3: To identify the gap of knowledge in the application of MgO as an expansive agent for self-healing concrete.	• application • MgO • expansive • agent • self-healing concrete.	• adoption, implantation, using • Magnesium Oxide • expanding • material, admixture • self-repairing concrete
RQ3:	Refer to RO3	Refer to RO3

What is next journey or direction of research in this field?		

Table 2.5: Searching string for each statement and its number of articles found.

Section	Search String (Scopus)	Number of the article (identification stage)
Topic	TITLE-ABS-KEY((“MgO” OR “Magnesium Oxide”) AND (“expansive” OR “expanding”) AND (“agent” OR “material” OR “admixture”) AND (“self-healing concrete” OR “self-repairing concrete”))	76
RO1	TITLE-ABS-KEY((“effectiveness” OR “efficiency” OR “efficacy” OR “capability” OR “performance” OR “strength”) AND (“MgO” OR “Magnesium Oxide”) AND (“agent” OR “material” OR “admixture”) AND (“self-healing concrete” OR “self-repairing concrete”))	478
RQ1:	TITLE-ABS-KEY((“best” OR “top” OR “premier” OR “optimum” OR “foremost”) AND (“form” OR “type”) AND (“MgO” OR “Magnesium Oxide”) AND (“expansive” OR “expanding”) AND (“agent” OR “material” OR “admixture”) AND (“self-healing concrete” OR “self-repairing concrete”))	29
RO2 & RQ2	TITLE-ABS-KEY((“application” OR “adoption” OR “implantation” OR “using”) AND (“MgO” OR “Magnesium Oxide”) AND (“self-healing concrete” OR “self-repairing concrete”))	474
RO3:	TITLE-ABS-KEY((“application” OR “adoption” OR “implantation” OR “using”) AND (“MgO” OR “Magnesium Oxide”) AND (“expansive” OR “expanding”) AND (“agent” OR “material” OR “admixture”) AND (“self-healing concrete” OR “self-repairing concrete”))	72

Table 2.6: Review criteria of the article in the screening stage.

Criteria	Inclusion	Exclusion
Timeline	2016-2020	before 2016
Document type	Article	Conference paper, review, book chapter, conference review, book, note, short survey, editorial and report
Publication stage	Final	Article in press
Language	English	Non-English

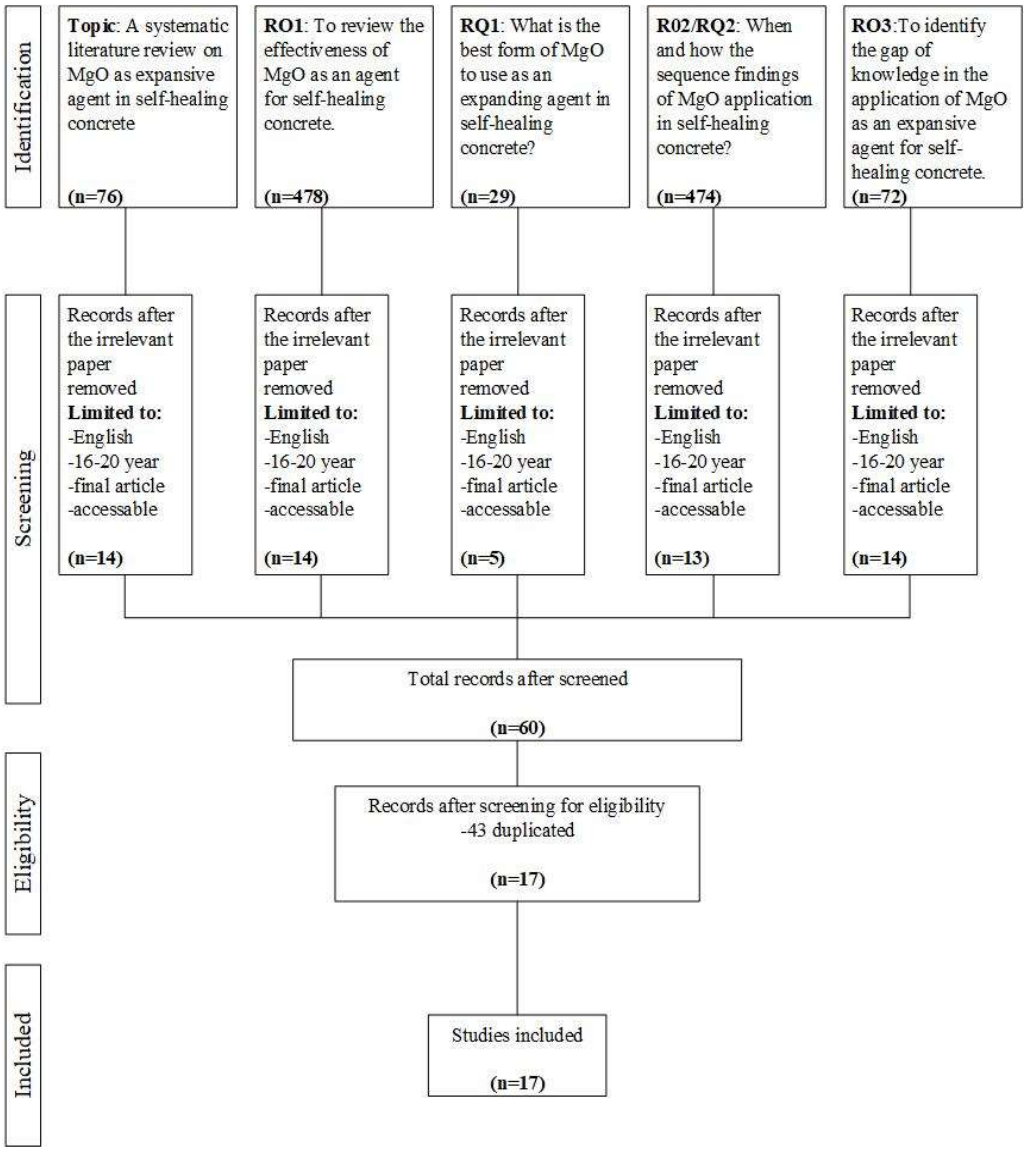

Plate 2.1: Flow diagram of the retrieved articles in systematic searching strategies.

2.3.2 Quality Assessment

Where applicable, the quality assessment is the methodological quality of the chosen literature and to avoid the publications of poor methodological quality (Štrukelj, 2018). The quality of systematic review is depended on the validity and quality of the review studies, which is the review is free from biases and the results are approximate to the truth (Bettany-Saltikov, 2012). Therefore, such poor research or study should be identified as such in the systematic analysis or completely omitted.

In this review, an assessment framework designed by Caldwell et al, (2011) had been used to assess the methodological quality of the studies. This appraisal framework can offer clarity and fairness when undertaking a review of a research paper for assessment purposes. Besides, it is also a framework that combines both quantitative and qualitative appraisal questions into one form. The framework provides a guideline with the extended explanation of each item (see Table 2.7) and it begins with questions that answer both quantitative and qualitative studies. However, since this review is a qualitative systematic review, therefore the quantitative question in the framework will be ignored and only the qualitative part will be addressed.

In this assessment, the total score for each study is calculated by adding one point for each "yes" and zero point for others, such as "no", "can't answer", and "not applicable," resulting in summary scores from 0 to 10 (see Table 2.8). To rate the quality of the articles, this assessment allocates the article into three categories: a score of 0–4 is classified as low quality, 5–7 indicates moderate quality, and 8–10 is regarded as high quality. In addition, there will be 17 articles waiting for appraising (see Table 2.9).

From the assessment, there are 16 out of 17 articles are categorized as high quality, which scores within 8 to 10. There is 1 article that is categorized as moderate

quality with a score of 7 (see Table 2.11). Among the questions, “Is the conclusion comprehensive?” get the least score compared to other questions. 10 articles successfully score this question, but 7 articles are not. This is due to those articles don’t have to include the recommendation for further study in the conclusion part. In contrast, the recommendation for further study should be included in the study because it gives convenience to the researcher so that they can answer the thing that is unknown, filling the gap of knowledge in a particular field. In conclusion, all the 17 articles have a mean score of 9.41, thus those articles are suitable for review.

Table 2.7: Questions in quality assessment and its description.

No.	Question	Explanation
1	Does the title reflect the content?	The title should be informative and reflect the focus of the study. It should make it simple for the reader to understand the content of the study. An inaccurate or misleading title can confuse the reader.
2	Are the authors credible?	Researchers should hold appropriate academic qualifications and be linked to a professional discipline relevant to the research.
3	Does the abstract summarize the key components?	The abstract should provide a brief description of the study. It should contain the study’s aim, methodology outline and main findings. The purpose of the abstract is to encourage the reader to decide if the study is of interest to them.
4	Are the background and study design identified and the rationale for undertaking the research clearly outlined?	The design of the study should be identified and the background. The author should provide a clear rationale for the research and the reader needs to consider whether it is satisfied to meet the aims of the study.
5	Is the literature review comprehensive and up to date?	The literature review should present the current state of knowledge relevant to the study and identify any gaps or conflicts. It should include key or classic studies on the topic as well as up-to-date literature.
6	Is the aim of the research clearly stated?	The aim of the study should be clearly defined and should deliver what the researcher is setting out to achieve.

7	Is the methodology identified and justified?	The researcher should state clearly which research strategy is adopting. A clear rationale for the choice should also be provided so that the reader can judge whether the chosen strategy is appropriate for the study.
8	Are the results presented in a way that is appropriate and clear?	Data presentation should be simple, easy to understand, and consistent.
9	Is the discussion comprehensive?	The results should be compared with previous research on the topic. The discussion should be balanced and avoid subjectivity.
10	Is the conclusion comprehensive?	Conclusions must be supported by the findings. The researcher should recognize any limitations to the study. There may also be recommendations for further research, or implications for practice in the relevant area.

Table 2.8: The articles assessment scoring mark.

Answer	Score
Yes	1
No, can’t answer, not applicable	0

Table 2.9: The rate of quality of the articles.

Categories	Total score
Low quality	0-4
Moderate quality	5-7
High quality	8-10

Table 2.10: The articles included in the review.

No	Title	Year
1	Self-healing of drying shrinkage cracks in cement-based materials incorporating reactive MgO	2016
2	Encapsulation of expansive powder minerals within a concentric glass capsule system for self-healing concrete	2016
3	Self-healing and expansion characteristics of cementitious composites with high volume fly ash and MgO-type expansive agent	2016
4	Nanosized magnesium oxide with engineered expansive property for enhanced cement-system performance	2017
5	The effect of nano-MgO on the setting time, autogenous shrinkage, microstructure and mechanical properties of high performance cement paste and mortar	2017
6	Development and recovery of mechanical properties of self-healing cementitious composites with MgO expansive agent	2017
7	The influence of MgO-type expansive agent incorporated in self-healing system of Engineered cementitious Composites	2017
8	Preparation and polymeric encapsulation of powder mineral pellets for self-healing cement based materials	2018
9	Autogenous self-healing of cement with expansive minerals-I: Impact in early age crack healing	2018
10	Autogenous self-healing of cement with expansive minerals-II: Impact of age and the role of optimised expansive minerals in healing performance	2019
11	Self-healing of cracks in mortars using novel PVA-coated pellets of different expansive agents	2020
12	Effects of UEA and MgO expansive agents on fracture properties of concrete	2020
13	Internally cured high performance concrete with magnesium based expansive agent using coal bottom ash particles as water reservoirs	2020
14	Hydraulic conductivity and self-healing performance of Engineered Cementitious Composites exposed to Acid Mine Drainage	2020
15	Durability of engineered cementitious composite exposed to acid mine drainage	2020
16	Sustainable High-Ductility Concrete with Rapid Self-Healing Characteristic by Adding Magnesium Oxide and Superabsorbent Polymer	2020
17	Effects of magnesia expansive agents on the self-healing performance of microcracks in strain-hardening cement-based composites (SHCC)	2020

Table 2.11: The assessment score of the article

No.	Question	Article																	TOTAL	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		
1	Does the title reflect the content?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	17	
2	Are the authors credible?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	17	
3	Does the abstract summarize the key components?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	17	
4	Are the background and study design identified and the rationale for undertaking the research clearly outlined?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	16	
5	Is the literature review comprehensive and up to date?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	17	
6	Is the aim of the research clearly stated?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	16	
7	Is the methodology identified and justified?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	17	
8	Are the results presented in a way that is appropriate and clear?	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	16	
9	Is the discussion comprehensive?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	17	
10	Is the conclusion comprehensive?	Y	N	Y	N	N	Y	N	Y	Y	Y	Y	N	N	Y	Y	Y	N	10	MEAN
	TOTAL	10	9	10	9	9	10	9	10	10	9	10	7	9	10	10	10	9		**9.41**

*Y = yes; N = no