THE INFLUENCE OF CRYSTALLINE ADMIXTURES INCLUSION ON SELF-HEALING CONCRETE

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THE INFLUENCE OF CRYSTALLINE ADMIXTURES INCLUSION ON SELF-HEALING CONCRETE

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ABSTRAK

Bahan campuran kristal dalam konkrit penyembuhan diri adalah topik utama kajian literasi komprehensif yang dibentangkan dalam disertasi ini. Tujuan kajian ini adalah untuk mengenal pasti kesan kemasukan campuran kristal ke atas konkrit penyembuhan sendiri. Kajian ini juga mengenal pasti jurang pengetahuan dalam aplikasi bahan campuran kristal untuk konkrit penyembuhan sendiri dan menilai prestasi bahan campuran kristal dalam konkrit penyembuhan sendiri. Untuk rujukan, konkrit penyembuhan sendiri boleh membaiki keretakan secara automatik tanpa bantuan luar untuk mendapatkan semula kekuatan dan ketahanan. Namun, pembentukan gel kalsium silikat hidrat (C-S-H) akan meningkatkan penyembuhan diri yang membantu mengisi retakan. Oleh itu, terdapat 18 artikel telah dikenal pasti dalam kajian ini daripada pangkalan data Scopus dan ScienceDirect. Strategi carian sistematik telah digunakan untuk menyaring artikel yang tidak berkaitan dan penilaian kualiti artikel juga digunakan untuk mengelakkan penerbitan kualiti metodologi yang lemah. Dalam kajian ini, kesan dan prestasi campuran kristal telah dibincangkan. Keputusan menunjukkan bahawa tindak balas penyembuhan konkrit dipengaruhi oleh proses penghidratan pada keretakan di konkrit. Keberkesanan kemasukan campuran kristal kemudiannya diperiksa, dan penemuan mendedahkan bahawa keadaan rendaman air, sentuhan air, dan prestasi basah/kering menunjukkan prestasi yang lebih baik daripada keadaan penyembuhan pendedahan di udara terbuka. Bahan campuran kristal digunakan sebagai bahan hidrofilik kerana cepat bertindak balas dengan air. Ketumpatan kalsium silikat hidrat (C-S-H) ditingkatkan lagi, yang menghalang atau mengurangkan penembusan air.

ABSTRACT

The crystalline admixture in self-healing concrete is the main topic of a comprehensive literature review presented in this final year project. The purpose of this review is to identify the effect of crystalline admixture inclusion on self-healing concrete. The review also identifies the knowledge gaps in the application of crystalline admixture for self-healing concrete and evaluates the performance of crystalline admixture in self-healing concrete. For information's future reference, self-healing concrete can automatically repair the crack without any outside assistance to regain strength and durability. Yet, the formation of calcium silicate hydrate (C-S-H) gel will enhance the self-healing helped to fill the crack. Therefore, there were 18 articles had been identified in this review from the Scopus and ScienceDirect database. Systematic searching strategies had been used to screen out irrelevant articles and the article quality assessment was also used to avoid publications of poor methodological quality. In this review, the effect and performance of crystalline admixture were discussed. Results indicated that the healing reaction of the concrete is influenced by the hydration process of the concrete cracks. The effectiveness of the inclusion of crystalline admixture was then examined, and the findings revealed that the conditions of water immersion, water contact, and wet/dry performance performed better than the healing condition of open-air exposure. Crystalline admixture materials are used as hydrophilic materials because of how quickly they react with water. The density of calcium silicate hydrate (C-S-H) is further increased, which prevents or reduces water penetration.

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LIST OF ABBREVIATIONS

BPC	Brazilian Portland Cement
CA	Crystalline admixture
CSA	Calcium Sulfoaluminate Admixture
DE	Defoamer admixture
ECC	Engineered Cementitious Composite
FRC	Fiber Reinforced Concrete
GBFS	Granulated Blast Furnace Slag
GGBS	Ground Granulated Blast Furnace Slag
HPFRC	High Performance Fiber Reinforced Concrete
MSC	Moderate Strength Concrete (water/cement between 0.3 and 0.4)
NSC	Normal Strength Concrete (water/cement between 0.5 and 0.6)
OPC	Ordinary Portland Cement
PC	Portland Cement
PLC	Portland Limestone Cement
PP	Polypropylene
PVA	Polyvinyl alcohol fiber
RCM	Rapid Chloride Migration
SAP	Superabsorbent Polymer
SFRC	Steel Fibre Reinforced Concrete
SHCC	Strain Hardening Cementitious Composites
SP	Superplasticizer
VA	Viscosity agent

CHAPTER 1

INTRODUCTION

1.1 Background

The phenomenon in concrete that repairs cracked concrete is self-healing (Danish et al., 2020). In concrete, around 20-30% of the cement particles are anhydrous, which reacts with water or moisture to produce hydration materials, which help to close the fracture owing to self-healing potential (Homma et al., 2009). Self-healing materials are applied to improve structural durability while minimizing maintenance, and repair expenses. It also protects the structures against costly repairs for the rest of their lives. (Series, 2014).

Materials like bacteria, crystalline admixtures, polymers, and fibers are frequently applied to concrete for self-healing purposes (Reddy et al., 2020). Among those aforementioned proprietary chemical admixtures, Crystalline Admixtures (CA) are one of the Permeability-Reducing Admixtures (PRAs) types as described by the American Concrete Institute Committee 212 (Gojević et al., 2021).

Autonomous crack healing through crystalline admixture results in modified calcium silicate hydrates and an insoluble pore-blocking precipitate when reacting with cement and water (Nasim et al., 2020). Crystalline admixtures are hydrophilic by nature and react rapidly with water. These compounds are composed of active compounds found in cement and sand. When mixed up with cement and water, crystalline admixture creates water-based insoluble crack blockage deposits that boost CSH density and water penetration. After the crack is formed, in the existence of moisture tricalcium silicate (C_3S) reacts and Calcium Silicate Hydrate (CSH) is deposited on crack walls, and it fills the crack (Guzlena & Sakale, 2019).

Particularly, self-healing can enhance the durability of concrete structures without any additional repair work, which has encouraged assorted studies on improving autogenous healing performance. In particular, many researchers have used supplementary cementitious materials (SCMs) and crystalline admixtures (CAs) to improve crack self-healing performance (Byoungsun & Young, 2019). Mix proportion, temperature, environmental humidity, and stress in the crack region can all impact the quality of concrete's self-healing capability. If the stress intensity is too severe, new cracks might form in the already healed crack location (Ferrara et al., 2014).

The usage of self-healing concrete in construction material today is growing because of the capability of crystalline admixtures that can give better results in the healing of cracks and increase the strength of concrete. However, the quality and performance of self-healing ability can be affected and concerned by mixed proportion, environmental humidity, level of temperature, and the stress on the crack region. Hence, this study will focus on the inclusion of crystalline admixture in self-healing concrete. Optimistically, this review will be beneficial to understand the effect of the inclusion of crystalline admixture on self-healing concrete.

1.2 Review questions

i. What is the effect of the concrete with crystalline admixture on the self-healing capability of the concrete?

ii. Under what conditions the performance of the concrete with the inclusion of crystalline admixture perform better?

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

1.3 Objectives of the systematic review

i. To investigate the effect of the concrete with crystalline admixture on the self-healing capability of the concrete.

ii. To examine under what condition the performance of the concrete with the inclusion of crystalline admixture perform better.

iii. To identify the gap of knowledge in the application of the inclusion of crystalline admixture for self-healing concrete.

1.4 Problem statements

Concrete constructions are the most usual form of building façades in Malaysia owing to their inexpensive construction costs, durability, and availability of raw materials. Meanwhile, the concrete crack will compromise the structure's endurance and integrity. On the other hand, people are not concerned about taking care of concrete at an early stage of maturation, and they are only aware of the crack after the building is completed. Therefore, this study is focusing on the effectiveness of the inclusion of crystalline admixture, how long it can effectively react, and the gap of knowledge in the inclusion of crystalline admixture in self-healing concrete. Therefore, this study would be able to provide a better understanding of the effect of the inclusion of crystalline admixture on the crack healing or self-healing in concrete.

1.5 Significance of the review

The ultimate purpose of this research is to better understand how crystalline admixture is used in self-healing concrete. The results of this research may then be used to determine the grade and proportion of crystalline additive to use in the concrete mix to get the best self-healing behavior. Finally, the literature review findings on the usage of crystalline admixture in self-healing concrete may be utilized as a guideline and reference in the proportioning of concrete mixes.

1.6 Organization of the report

This dissertation is divided into five main chapters, each of which covers a distinct issue relating to the topic. The reader may understand the dissertation in shallow also deep by following the chapters order. From chapter 1 through chapter 5, the following is an overview of the chapters in this dissertation.

The first chapter is Chapter 1. The study's outline is presented in the first chapter. The background of the study, review questions, objectives, problem statements, and significance of the study will be explained in this chapter.

The methodological section of the study is discussed in Chapter 2. Before conducting this review, it will discuss the systematic literature review planning procedure. The procedure, review questions, searching strategies, quality assessment, data extraction, data synthesis, and review reporting will be explained in this chapter.

Data extraction and data synthesis are defined in Chapter 3 for a more detailed explanation. This chapter covers some general information as well as the extraction and synthesis methods. These steps are critical since they are the last ones before the review's summary or conclusion.

The information gained from the research paper studied is discussed and analyzed in Chapter 4. The information gathered from the article will be explained in this review to answer the review question. Furthermore, the divergences between the papers and the knowledge gap between those articles published will be clarified.

Finally, after evaluating the papers and assessing the knowledge gap discovered in this study, Chapter 5 gives the study's conclusions. This chapter also includes suggestions for further research.

CHAPTER 2

SYSTEMATIC LITERATURE REVIEW: A METHODOLOGY

2.1 Introduction

A literature review is a comprehensive summary of major works and other material on a certain topic. Scholarly journal articles, books, government reports, Web sites, and other sources could also be used in the review. Each source is summarized, evaluated, and reviewed in the literature review (Cleyle & Booth, 2006). In other words, the literature review can be defined as a simplified summary of a research topic that comprises synthesis and summary at the same time. A systematic review's goal is to find all empirical data that answers a certain research question or hypothesis and meets the pre-specified inclusion criteria (Snyder, 2019). A systematic review is indeed a thorough analysis of previous research that answers a specific topic. The review searches identify, select, appraise, and synthesize research evidence relevant to the topic in a systematic, reproducible, and bias-free manner. The best source of scientific evidence is recognized as systematic reviews (Donohue et al., 2021).

Before the systematic review is conducted, the criteria should be precisely defined in a properly specified protocol or plan. It is a transparent, thorough search that spans several databases and grey literature and can be replicated by other academics. It entails devising a well-thought-out search strategy that focuses on a certain topic or answers a specific query. Within established timeframes, the review indicates the sort of information searched, criticized, and reported. The review must include the search terms, search tactics (including database names, platforms, and search dates), and limits.

2.2 Planning of SLR

The systematic review methodology will be defined first in the planning phase, followed by the design of review questions. The purpose of this study is to evaluate the use of crystalline admixture in self-healing concrete. Some background or understanding of the title is essential since it may help in the formation of a quick summary on how to develop sections such as the objective, review question, and methodology. A systematic review, on the other side, has a specific process for conducting the review, and a defined review protocol must be defined before the review can begin. The planning, conducting, and reporting stages are the three steps that may be summarised in this review protocol from the beginning to the finish of the review. It explains the protocols for each step so that the review may proceed smoothly, and author bias can be prevented while presenting the topic.

2.2.1 Review protocol

A detailed protocol is required before conducting a systematic literature review as it will serve as a guide for the review. The creation of a protocol is an important part of the systematic review process. The objective, hypothesis, and planned methods of systematic reviews should all be specified in a protocol; few reviews report whether a protocol exists. The understanding and evaluation of review procedures, as well as the identification and selective reporting in completed reviews, can all be aided by detailed, well-described protocol (Moher et al., 2016).

The review protocol, literature selection, and data extraction, analysis, and summarization approaches vary amongst different types of reviews (Xiao & Watson, 2019). Because the protocol provides a clear description and explanation of the processes that should be done, it will be simple to define the project's objectives, review questions, and purpose (Jesson et al., 2011). The review protocol specifies the

procedures to be followed during the review. It is necessary to make decisions on the review question, inclusion criteria, search method, study selection, data extraction, quality assessment, data synthesis, and dissemination plans. The possibility of bias in the review is reduced if the methodologies are specified ahead of time.

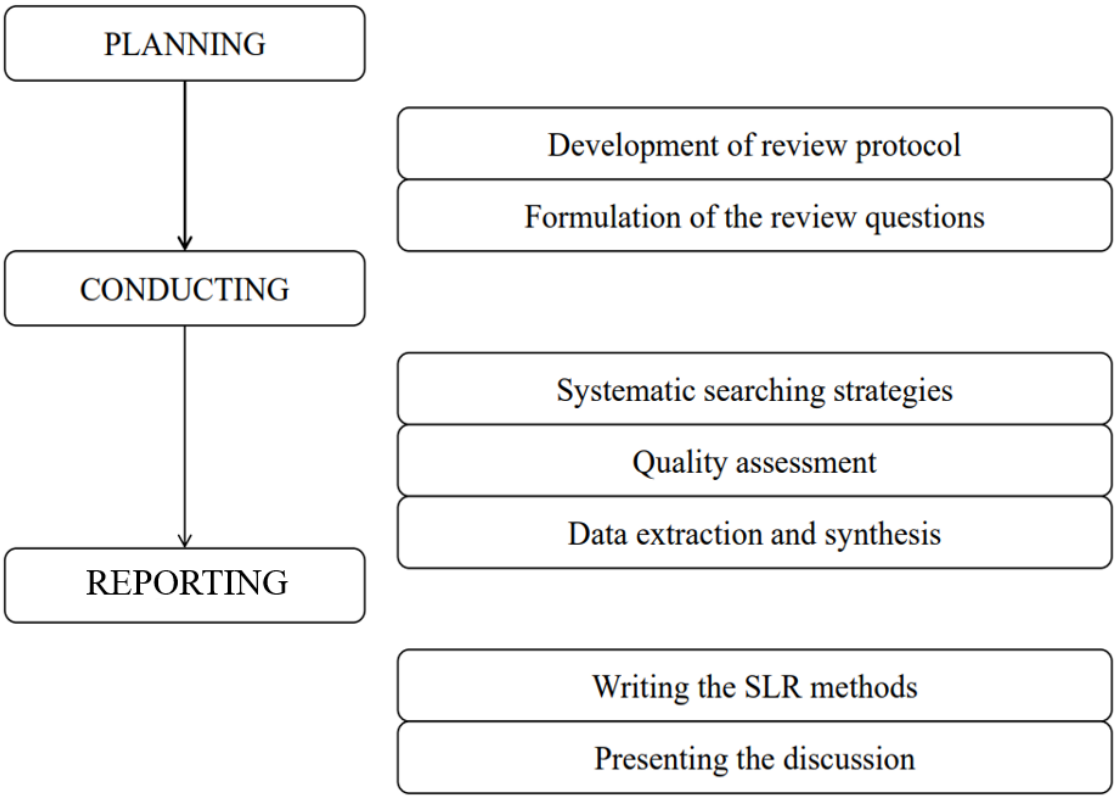

Figure 2.1: Flow chart of review protocol.

The protocol is divided into three stages: planning, conducting, and reporting (Figure 2.1). Once the study's title has been decided, a review process must be developed during the planning stage. It is more focused on the exploring and processing of the research article during the conducting stage. By applying the key term from the topic and objective, systematic searching strategies are performed to identify the relevant article from the database. After that, the articles are filtered to remove the unnecessary and duplicated ones, leaving only the most important ones.

A quality assessment for the selected article will be conducted after the article has been found in the database. The purpose of evaluating the quality of systematic reviews is to determine the reliability of the findings. Quality is described as the extent to which standards are in place to protect all parts of study design and implementation against systematic, unsystematic, and inferential error. As a result, the review is less biased and more credible.

The technique for extracting data from each article, such as the author, the study's goal, and the study's result, is called data extraction. In the meantime, the data synthesis section oversees coordinating all the articles to find any answers to the review question. As an outcome, the data taken from each article will then be presented in a table such that the differences and similarities between each may well be easily seen and reviewed.

In reporting stage, it is the procedure to summarize, synthesize, and present the appropriate response to the review questions. The report will be examined under the themes or categories of thematic analysis in this study. Because each article will contain a table of thematically synthesized material, it will be simple for us to answer the review question that was specified during the planning stage and to interpret the knowledge gap between the articles. Aside from that, the recommendation might be made for future researchers in the field or on the topic to help them enhance their work.

2.2.2 Formulation of review question

Specifying the review question leads to identifying which types of studies are best suited to answering it and developing criteria for including them in the review. This is also known as the eligibility criterion or inclusion criteria. The criteria could be related to the review topic, the studies' research methodologies, specific groups, settings, time constraints, geographical locations, intervention types, or something else entirely (Wildridge & Bell, 2002). Systematic reviews focus on specific research questions rather than a broad topic or problem of interest, and they contain specific criteria for the studies that are used to answer the research questions. This is also known as the eligibility criteria or inclusion criteria (Cleyle & Booth, 2006).

2.3 Conducting SLR

The researcher will outline the search strategy depending on the review paper's goal at this stage of the process. The review paper's goals are derived from the review question, which was previously specified in the review question formulation. The quality criteria will then be developed to refine the inclusion article in the search before data extraction and synthesis. When doing a systematic review, it is critical to collect as much research as possible that is relevant to the study's aims or topics. To broaden the search, a searching strategy will be used, including establishing a replacement for the aim and the review question and filtering for eligible articles.

2.3.1 Systematic searching strategies

A very sensitive search in a systematic review will look for any potentially relevant article. A systematic review search will include many synonyms and variants of search terms, add search filters with care, and look for multiple resources, databases, and grey literature, such as reports. The method (Figure 2.2) was used to obtain the search strings used in this review.

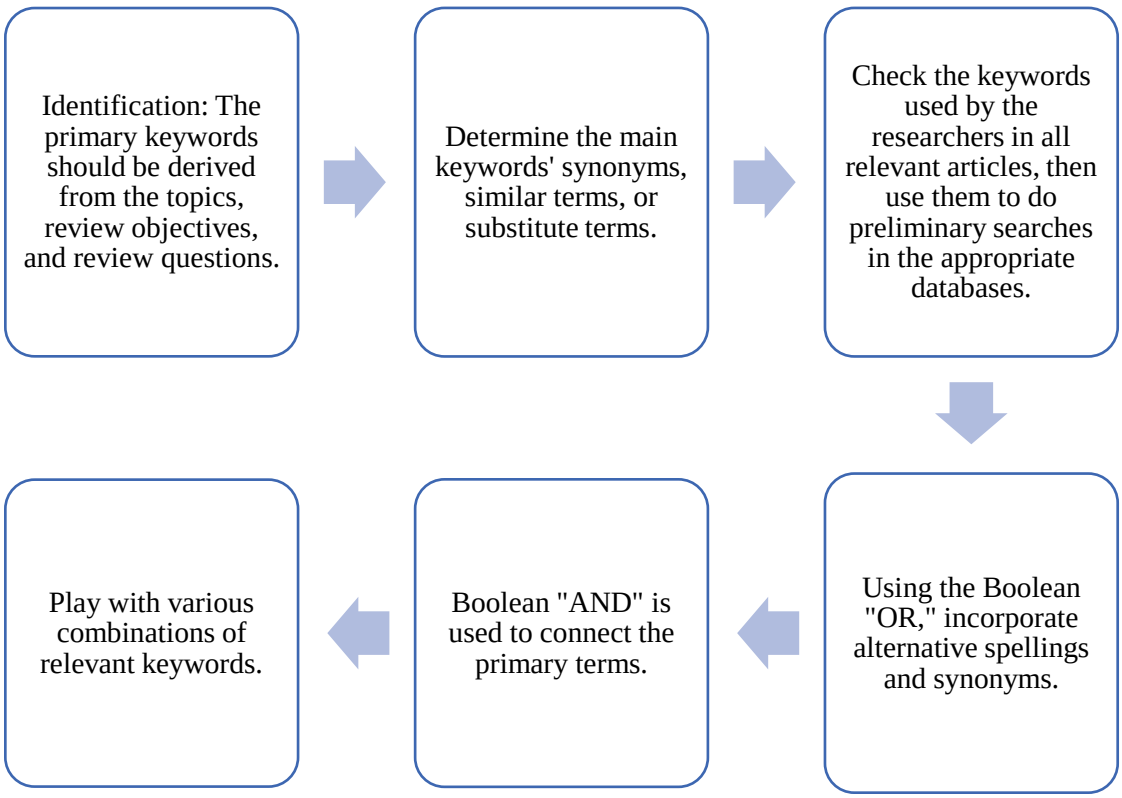

Figure 2.2: Flow of method used to obtain the search strings.

The database sources used were Scopus and Science Direct. From the flow of method used to obtain the search strings, it will be executed to the database mentioned above.

2.3.1(a) Identification

The first part of systematic searching strategies is identification. The goal of this section is to expand the list of keywords linked to this topic to diversify the search approach and find more related and topic-focused publications and journals. Table 2.1 shows the enriched keywords from the title and review questions that will be used in this literature review. From Table 2.1, the enriched keyword will serve as input to be searched in the selected databases to search the related articles and journals for the review such as Science Direct and Scopus.

Table 2.1: Identification of keywords.

Section	Main keywords	Enriched keywords
Title: The influence of crystalline admixtures inclusion on self-healing concrete	○ Inclusion ○ Crystalline admixture ○ Self-healing concrete	○ Addition, presence ○ Crystalline admixture = CA ○ Self-repairing concrete
RO1: To review and investigate the effect of the concrete with crystalline admixture on the self-healing capability of the concrete.	○ Effect ○ Crystalline admixture ○ Self-healing ○ Capability	○ Impact ○ Crystalline admixture = CA ○ Self-repairing ○ Ability
RQ1: What is the effect of the concrete with crystalline admixture on the self-healing capability of the concrete?	○ Effect ○ Crystalline admixture ○ Self-healing ○ Capability	○ Impact ○ Crystalline admixture = CA ○ Self-repairing ○ Ability
RO2: To examine under what condition the performance of the concrete with the inclusion of crystalline admixture on self-healing concrete	○ Effective ○ Inclusion ○ Crystalline admixture ○ Self-healing concrete	○ Efficient, practical ○ Addition, presence ○ Crystalline admixture = CA ○ Self-repairing concrete
RQ2: Under what conditions the performance of the concrete with the inclusion of crystalline admixture perform better?	○ Effective ○ performance ○ Crystalline admixture ○ Self-healing concrete	○ Efficient, practical ○ Addition, presence ○ Crystalline admixture = CA ○ Self-repairing concrete
RO3: To identify the gap of knowledge in the application of the inclusion of crystalline admixture for self-healing concrete.	○ Application ○ inclusion ○ Crystalline admixture ○ Self-healing concrete	○ Adoption, implementation ○ Addition, presence ○ Crystalline admixture = CA ○ Self-repairing concrete

2.3.1(b) Screening

Screening is the second step in the systematic literature review strategy. This section will concentrate on eliminating the undesirable criteria from articles and journals and narrowing the scope of the search to obtain the desired type of articles and journals by including the helpful criteria. Before searching, all the criteria should be established and comprehended. The filtering procedure is often based on the timeline, publication, type, and language as shown in Table 2.2.

Table 2.2: Screening criteria.

Criteria	Inclusion	Exclusion
Timeline	2022-2018	Before 2018
Publication type	Review articles, research articles	Conference paper, conference review, conference proceeding, short survey, note, newspaper, editorial, and report
Language	English	Non-English
Subject Area	Engineering, Material Science, Physics and Astronomy, Chemical Engineering	Business, Management and Accounting, Energy, Environmental Science

2.3.1(c) Develop a searching string

The enriched keywords from Section 2.3.1.(a) and the screening criteria from Section 2.3.1.(b) were used and applied in this section of the searching strings. As a result, Table 2.3 below displays the title's search strings; Table 2.4 shows the search strings for RO1 and RQ1, Table 2.5 shows the search strings for RO2 and RQ2, and Table 2.6 shows the search strings for RO3 and RQ3.

Overall, the word “inclusion” is linked with “addition” and “presence”. Then, the word “self-healing concrete” is linked with the word “self-repairing concrete” while the word “crystalline admixture” will not be linked with “CA” since the title and general information like abstract will not use the abbreviation hence will not give a

significant effect on search. Next, the term “affect” is linked with the word “impact”. The word “self-healing” is linked with the word “self-repairing”, while the word “capability” is linked with the word “ability”. The word “effective” is linked with the word “efficient” and “practical”. Lastly, the word “application” is linked with the word “adoption” and “implementation”.

There are some differences between the Scopus and Science Direct search strings. First, it is the beginning of searching that is dependent on the database command, such as the study field "TITLE-ABS-KEY" as an opening to searching in SCOPUS to search through the title, abstract, and keywords, although Science Direct does not. Second, the length of search strings in Science Direct is limited to eight Boolean connectors per field, which means that each field can only include four terms.

Table 2.3: Searching strings developed for the title.

Database	Searching strings
Scopus	TITLE-ABS-KEY ((“inclusion" OR "addition" OR "presence") AND ("crystalline admixture") AND ("self-healing concrete" OR "self-repairing concrete"))
Science Direct	(("inclusion" OR "addition" OR "presence") AND ("crystalline admixture") AND ("self-healing concrete" OR "self-repairing concrete"))

Table 2.4: Searching strings developed for SLR, RO1 & RQ1.

Database	Searching strings
Scopus	TITLE-ABS-KEY ((“effect" OR "impact”) AND ("crystalline admixture") AND ("self-healing" OR "self-repairing") AND (“capability” OR “ability”) AND (“concrete”))
Science Direct	((“effect" OR "impact”) AND ("crystalline admixture") AND ("self-healing" OR "self-repairing") AND (“capability” OR “ability”))

Table 2.5: Searching strings developed for SLR, RO2 & RQ2.

Database	Searching strings
Scopus	TITLE-ABS-KEY ((“condition" OR "environment”) AND (“inclusion” OR “addition” OR “presence”) AND ("crystalline admixture") AND ("self-healing concrete" OR "self-repairing concrete"))
Science Direct	((“effective" OR "efficient” OR “practical”) AND (“inclusion” OR “addition” OR “presence”) AND ("crystalline admixture") AND ("self-healing concrete" OR "self-repairing concrete")

Table 2.6: Searching strings developed for SLR, RO3.

Database	Searching strings
Scopus	TITLE-ABS-KEY ((“application" OR "adoption” OR “implementation”) AND (“inclusion” OR “addition” OR “presence”) AND ("crystalline admixture") AND ("self-healing concrete" OR "self-repairing concrete"))
Science Direct	((“application" OR "adoption” OR “implementation”) AND (“inclusion” OR “addition” OR “presence”) AND ("crystalline admixture") AND ("self-healing concrete" OR "self-repairing concrete"))

2.3.1(d) Eligibility

After the selected sources have been collated, eligibility is determined. The eligibility of the retrieved articles is usually manually checked to confirm that all the remaining articles (after the screening procedure) meet the criteria. Eligibility can be determined by reading the titles and abstracts of the papers, and if there is still a doubt about the articles' relevance to the study, the content of the articles must be checked.

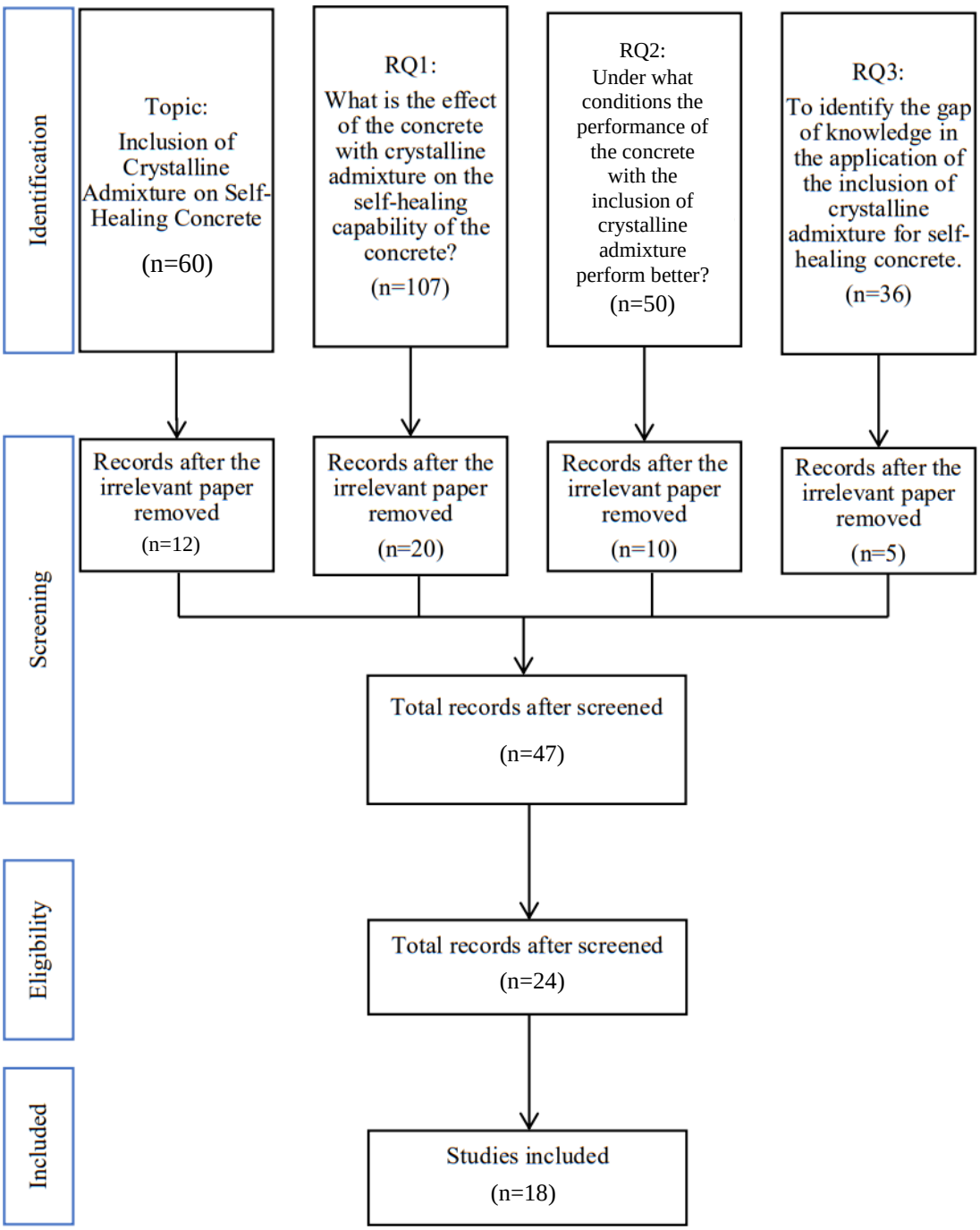

Figure 2.3: PRISMA flow diagram.

All procedures involved in systematic searching strategies were then reported using the PRISMA flow diagram as in Figure 2.3. The eligibility stage will begin when the screening stage is completed. All the articles and literatures retrieved by each search statement are reviewed for duplication at this phase. Duplicate articles and literatures will be excluded, leaving only the articles that need to be reviewed.

2.3.1(e) Quality assessment criteria

The eligibility questions for the whole quality assessment criteria were created by referring to the SLR done by Caldwell et al., (2011), in which the papers address a specific framework for criticizing health research. As a result, in this instance, the research is employed as a teaching tool as well as an assessment tool. As a result, it is utilized as an assessment tool in this case study. This framework received some feedback from the students as shown in Figure 2.4.

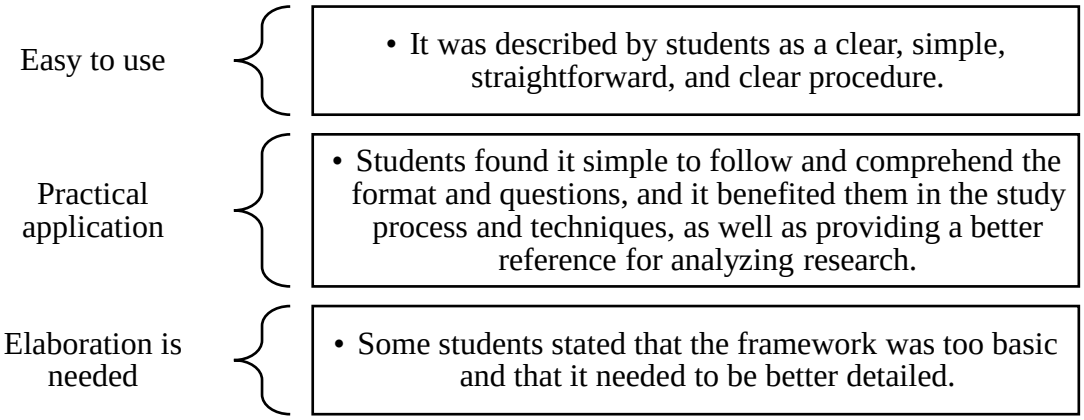

Figure 2.4: Feedback received by Caldwell et al., (2011).

The framework begins with questions that both quantitative and qualitative research can answer, as indicated in Table 2.7, and it gives a guideline with a comprehensive explanation of each item. However, because this is a qualitative systematic review, the quantitative issues in the framework will be ignored, and only the qualitative aspect of the framework will be addressed.

Table 2.7: Questions in quality assessment and its description.

No.	Question	Description
1	Does the title reflect the content?	The title should be descriptive and represent the study's objective. It should make the study's information easy to comprehend for the reader. A title that is incorrect or misleading might lead to reader confusion.
2	Are the authors credible?	Researchers should have valid educational qualifications and be affiliated with a professional field relevant to the study.
3	Does the abstract summarize the key components?	The research should be briefly described in the abstract. It should include the study's purpose, methods, and main points. The abstract's goal is to persuade the reader to decide whether 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 study's design and background should be determined. The author should clearly explain the justification for the study, and the reader should decide whether it is sufficient to achieve the study's objectives.
5	Is the literature review comprehensive and up to date?	The literature review should summarize the current field of knowledge in the field and point out any gaps or inconsistencies. It should include both significant and classic works on the subject as well as current research.
6	Is the aim of the research clearly stated?	The study's goal should be well-defined, and it should fulfill what the researcher set out to do.
7	Is the methodology identified and justified?	The researcher should identify the research strategy he or she is using. A clear reason for the decision should also be supplied so that the reader may determine whether the method chosen is appropriate for the study.
8	Are the results presented in a way that is appropriate and clear?	Data should be presented in a straightforward, consistent manner.
9	Is the discussion comprehensive?	The result should be compared to prior studies on the topic. The discussion should be fair and objective, with no subjectivity.
10	Is the conclusion comprehensive?	Conclusions must be supported by the findings. The researcher should be aware of the study's limitations. There might also be suggestions for more study or implications for practice in the relevant field.

The overall score for each research is derived by adding one point for each "yes" and zero points for "no," "can't answer," and "not applicable," yielding summary scores ranging from 0 to 10 as shown in Table 2.8. This rating divides the articles into three groups, with a score of 0-4 indicating low quality, 5-7 indicating moderate quality, and 8-10 indicating good quality as in Table 2.9. Table 2.10 shows the list of articles included in the review to be assessed. From the assessment in Table 2.11, all the articles score at least 8 score, and the mean value is 9 which is considered as good quality.

Table 2.8: The articles assessment scoring marks.

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

Table 2.9: Quality rate of the articles.

Categories	Score
Low quality	0-4
Moderate quality	5-7
Good quality	8-10

Table 2.10: List of articles included in the review.

No	Year	Title	Authors, and Year of Publication
1	2022	Microstructural characterization of self-healing products in cementitious systems containing crystalline admixture in the short- and long-term	(de Souza Oliveira et al., 2022a)
2	2020	Self-healing efficiency and crack closure of smart cementitious composite with crystalline admixture and structural polyurethane	(Xue et al., 2020)
3	2022	Self-healing of concrete containing different admixtures under laboratory and long-term real outdoor expositions based on water permeability test	(Lauch et al., 2022)
4	2021	Effect of chloride ingress on self-healing recovery of smart cementitious composite incorporating crystalline admixture and MgO expansive agent	(Xue et al., 2021)
5	2021	Effect of crystalline admixture and polypropylene microfiber on the internal sulfate attack in Portland cement composites due to pyrite oxidation	(Dobrovolski et al., 2021)
6	2021	Effect of crystalline admixtures on mechanical, self-healing and transport properties of engineered cementitious composite	(Zhang et al., 2021a)
7	2021	Effect of fly ash on the self-healing capability of cementitious materials with crystalline admixture under different conditions	(Wang et al., 2021b)
8	2021	Effect of healing products on the self-healing performance of cementitious materials with crystalline admixtures	(Zhang et al., 2021a)
9	2021	The Effect of Crystalline Waterproofing Admixtures on the Self-Healing and Permeability of Concrete	(Gojević et al., 2021)
10	2020	Effect of crystalline admixture, fly ash, and PVA fiber on self-healing capacity of concrete	(Nasim et al., 2020b)
11	2020	Effect of granulated blast furnace slag on the self-healing capability of mortar incorporating crystalline admixture	(G. Li et al., 2020)
12	2020	Synergetic effect of superabsorbent polymer (SAP) and crystalline admixture (CA) on mortar macro-crack healing	(D. Li et al., 2020)
13	2019	Assessment of self-healing and durability parameters of concretes incorporating crystalline admixtures and Portland Limestone Cement	(Azarsa et al., 2019a)
14	2019	Investigating a new method to assess the self-healing performance of hardened cement pastes containing supplementary cementitious materials and crystalline admixtures	(Byoungsun & Young, 2019)
15	2019	Macro mechanical properties of self-healing concrete with crystalline admixture under different environments	(Reddy & Ravitheja, 2019)
16	2018	Effect of a crystalline admixture on the self-healing capability of high-performance fiber reinforced concretes in service conditions	(Escoffres et al., 2018)

17	2018	A methodology to assess crack-sealing effectiveness of crystalline admixtures under repeated cracking-healing cycles	(Cuenca et al., 2018)
18	2018	Self-healing capability of cementitious materials with crystalline admixtures and super absorbent polymers (SAPs)	(Park & Choi, 2018)

Table 2.11: The assessment score of the articles.

No	Title	Assessment Criteria Questions										Total
		1	2	3	4	5	6	7	8	9	10	
1	Microstructural characterization of self-healing products in cementitious systems containing crystalline admixture in the short- and long-term	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	9
2	Self-healing efficiency and crack closure of smart cementitious composite with crystalline admixture and structural polyurethane	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
3	Self-healing of concrete containing different admixtures under laboratory and long-term real outdoor expositions based on water permeability test	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	9
4	Effect of chloride ingress on self-healing recovery of smart cementitious composite incorporating crystalline admixture and MgO expansive agent	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
5	Effect of crystalline admixture and polypropylene microfiber on the internal sulfate attack in Portland cement composites due to pyrite oxidation	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	9
6	Effect of crystalline admixtures on mechanical, self-healing and transport properties of engineered cementitious composite	Y	Y	Y	Y	Y	N	Y	Y	Y	N	8
7	Effect of fly ash on the self-healing capability of cementitious materials with crystalline admixture under different conditions	Y	Y	Y	Y	Y	N	Y	Y	Y	N	8
8	Effect of healing products on the self-healing performance of cementitious materials with crystalline admixtures	Y	Y	Y	Y	Y	N	Y	N	Y	Y	8
9	The Effect of Crystalline Waterproofing Admixtures on the Self-Healing and Permeability of Concrete	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10

10	Effect of crystalline admixture, fly ash, and PVA fiber on self-healing capacity of concrete	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
11	Effect of granulated blast furnace slag on the self-healing capability of mortar incorporating crystalline admixture	Y	Y	Y	Y	Y	N	Y	Y	Y	N	8
12	Synergetic effect of superabsorbent polymer (SAP) and crystalline admixture (CA) on mortar macro-crack healing	Y	Y	Y	Y	Y	N	Y	Y	Y	N	8
13	Assessment of self-healing and durability parameters of concretes incorporating crystalline admixtures and Portland Limestone Cement	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
14	Investigating a new method to assess the self-healing performance of hardened cement pastes containing supplementary cementitious materials and crystalline admixtures	Y	Y	Y	Y	Y	N	Y	Y	Y	N	8
15	Macro mechanical properties of self-healing concrete with crystalline admixture under different environments	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
16	Effect of a crystalline admixture on the self-healing capability of high-performance fiber reinforced concretes in service conditions	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
17	A methodology to assess crack-sealing effectiveness of crystalline admixtures under repeated cracking-healing cycles	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	10
18	Self-healing capability of cementitious materials with crystalline admixtures and super absorbent polymers (SAPs)	Y	Y	Y	Y	Y	N	Y	Y	Y	N	8
	Total											Mean: 9

2.3.2 Data extraction and data synthesis

Before assessing the quality of the research or literature, data must be extracted. The process of obtaining the relevant information from an article to fulfil the review objectives and review question is known as data extraction. Each article's relevant details are documented in extraction form or framework. The essential features of the articles, such as the objective, methodology, finding, and so on, is highlighted in a certain way. The most traditional approach to begin the data extraction process is to highlight the relevant portion of the article and then input it into the data extraction form for each article. Furthermore, revising the content further might help to prevent missing relevant material related to the issue.

Data synthesis, which comes after the data extraction phase, is perhaps the most difficult part in a systematic literature review. The synthesis of data is a stage in the process of determining the answer to the review question. To answer the review question, the data collected in the data extraction form must be connected. Information can be synthesised in a new order to contribute to knowledge or to fill a knowledge gap. Furthermore, there is no universally accepted method for synthesising information; it varies depending on the type of review and the topic matter. A good synthesis approach, such as chronological analysis or theme analysis, can simply provide a relevant summary result for the review.