JCBM (2024) 7(1) 1-15

University of Cape Town
Journal of Construction Business and Management
http://journals.uct.ac.za/index.php/jcbm

Quality Management In Ready-Mix Concrete Production In Zambia

[1]Arthur S. Bweupe and [2]Balimu Mwiya
[1&2]School of Engineering, Civil and Environmental Engineering Department, University Of Zambia

Received 04 January 2024; received in revised form 08 April 2024, 02 May 2024, 23 May 2024; accepted 23 May 2024
https://doi.org/10.15641/jcbm.7.1.1508

Abstract

The construction industry, a significant contributor to global economies, is projected to yield substantial economic output by 2030 of around $135 trillion. Central to construction is concrete, a widely used material. Ready-mix concrete (RMC), a specialised form of concrete, is gaining prominence due to its rapid setting and superior quality. In Zambia, the increasing demand for RMC highlights the need for stringent quality management to hedge potential structural risks. This study aimed to determine the quality management in ready-mix concrete production in Zambia. Employing a parallel convergent mixed-methods research design to achieve the objectives, qualitative data was collected through semi-structured interviews and desk study and quantitative data was gathered through a structured questionnaire and an observation checklist. The findings of the study reveal that while guidelines exist, adherence varies. Regulatory bodies for standards, engineering and construction play pivotal roles in overseeing RMC quality. However, their execution faces inconsistencies and challenges due to limited resources and a lack of sense of responsibility. Quality control practices were investigated unveiling variations in forward, immediate, and retrospective control phases. Notable trends in proper storage and equipment calibration showed a commitment to precision. Immediate control practices, encompassing sampling and non-compliance management, demonstrated both positive aspects and areas for improvement. Retrospective control showed commitment to comprehensive strength testing and minimal towards split cylinder testing and on-site slump evaluation. In the realm of quality assurance (QA), RMC facilities show substantial adherence to documented QA standard operating procedures and thorough raw material inspections. However, deficiencies in batching and mixing practices and limited adoption of modern weighing systems require improvement. The study recommends creating an industry association for collaboration, enhancing standardised practices, introducing third-party quality audits, and proposing compulsory RMC standards to boost progress in the Zambian RMC industry.

Keywords: Quality Management, Ready Mix Concrete, Observation, Desk Study, Zambia.

1. Introduction

Construction plays a distinctive role in long-term economic growth by increasing a country's physical infrastructure and providing adequate employment opportunities through its close interlinkages with other sectors (Sun *et al.*, 2013). In recent decades, the construction sector has experienced continuous growth, and it has made a significant and exceptional contribution to the growth of both the global economy as a whole and the economies of individual nations (Gizaw, 2021). Furthermore, it is projected that in this decade leading to 2030, there will be an estimated cumulative sum of $135 trillion in construction activity, propelled by exceptional levels of government economic support and the rapid advancement of major global infrastructure initiatives (Oxford Economics, 2021).

Concrete, an extremely vital component of any infrastructural establishment, is one of the most widely used construction materials worldwide. Due to its adaptability and versatility, concrete, a robust, long-lasting and endorsed building material for hundreds of years, retains its position as the most common, affordable, and essential material for the

[1] Corresponding Author
Email address: bweupearthur@gmail.com

construction of various infrastructures and it unsurprisingly makes up the greater part of structures, particularly for multi-storey buildings and infrastructure, where it contributes between 30 and 50 per cent of the entire total cost (Ravindrarajah, 2010; Naiknavare *et al*., 2018). Clearly, concrete stands out as the fundamental construction material that has significantly influenced the contemporary world, and it holds a pivotal position in constructing a sustainable future ahead serving as a cornerstone in meeting the requirements for sustainable and thriving communities by facilitating essential infrastructure, homes, and access to clean water, as well as clean and renewable energy (GCCA, 2021).

A specialised type of concrete known as ready mix concrete (RMC) produced at centralised batching plants according to the specification of the customer and delivered to the site is a preferred material due to its affordability, eco-friendliness and high strength (Shah *et al,*. 2014). As shown in a study carried out by Al-Saedi *et al*. (2019), the main advantages of RMC over site mixed concrete are its high quality, low life cycle cost, speedy production, and environmental friendliness. However, when various factors compromise RMC quality, unusable concrete is produced. As much as RMC emerges as an advantageous material in congested sites where setting up a batching plant is challenging, the absence of proper and effective quality monitoring systems in most of these batching plants adversely affects the quality of the concrete produced (Naiknavare *et al,*. 2018). According to a study by Achiso (2021), it was found that improper storage of the materials used to make concrete, the quality of the fine aggregates, the plant feed systems, the inadequate material testing facilities and labs at the plants, the use of contaminated groundwater for concrete mixing and as well as the mode of concrete transportation were the key contributing factors which affect the quality of ready-mixed concrete. In addition, material source, mix design, curing method and lack of periodic calibration of batching plants also significantly impact the quality of RMC. Furthermore, increased travel time from the batching plant to the site of placement contributes to the increase in slump value and decrease in concrete strength (Hossain and Rahman, 2013).

Following the increased popularity of RMC, there is a need to control and restrict the factors that may compromise its quality by instituting the appropriate quality management systems. This highlights the aim of this paper which is to determine the quality management of ready-mix concrete (RMC) production in Zambia. To achieve this aim, the following objectives were formulated:

- To examine existing guidelines in quality management of RMC in Zambia.
- To assess the role of regulatory bodies in the quality management of RMC in Zambia.
- To investigate the quality control and quality assurance practices in RMC production in Zambia.

2. Literature Review

2.1. Ready Mix Concrete

Ready Mix Concrete (RMC) is regarded as a specialised concrete whose components, including cement, aggregates, water, and admixtures, are all weighed at a production facility and mixed in either a central or truck mixer before being delivered to a site in plastic form, needing no additional treatment before placement and settling (Naiknavare *et al*., 2018). The use of RMC supplied as per the customer's mix design has increased recently since it sets and hardens more rapidly and is of greater quality than manually mixed in-situ concrete (Mayteekrieangkrai and Wongthatsanekorn, 2015). RMC is the preferred material in contemporary engineering and construction projects because it offers solutions to specific customer challenges and ensures product satisfaction by supplying concrete of the necessary and acceptable quality, which has an immediate impact on the structural integrity of buildings and structures (Baheti et al., 2017). Due to its strength, adaptability for diverse purposes, and also because it is made in a factory setting which allows for tight control of all manufacturing and transportation processes for fresh concrete, RMC is currently one of the most commonly used construction materials (Baheti *et al*., 2017).

2.1.1. Types of RMC

According to Biswas and Sen (2016) and Chakraborty and Farhan (2022), there are 3 types of RMC based on how various components are mixed namely transit mixed concrete, shrink-mixed concrete, and central mixed concrete:

A. Transit-mixed concrete

This is a kind of RMC also known as dry-batched concrete whose components, except for water, are weighed at a central plant and thoroughly mixed in the truck during transportation and water is only introduced to the mix right before placement on site.

B. Shrink mixed concrete

This type of concrete is partially mixed in a stationary plant mixer then a drum mixer mounted on the delivery truck completes the mixing on the way to the site. The amount of mixing to be carried out on the way is dependent on how much mixing is done at the central plant.

C. Central mixed concrete

Before being loaded into transit truck mixers for high-slump concrete or dump trucks for low-slump concrete, this type of concrete is thoroughly mixed in a central mixing facility, also known as a wet
.
batch or premix plant The three types of RMC based on how various components are mixed are shown in Figure 1.

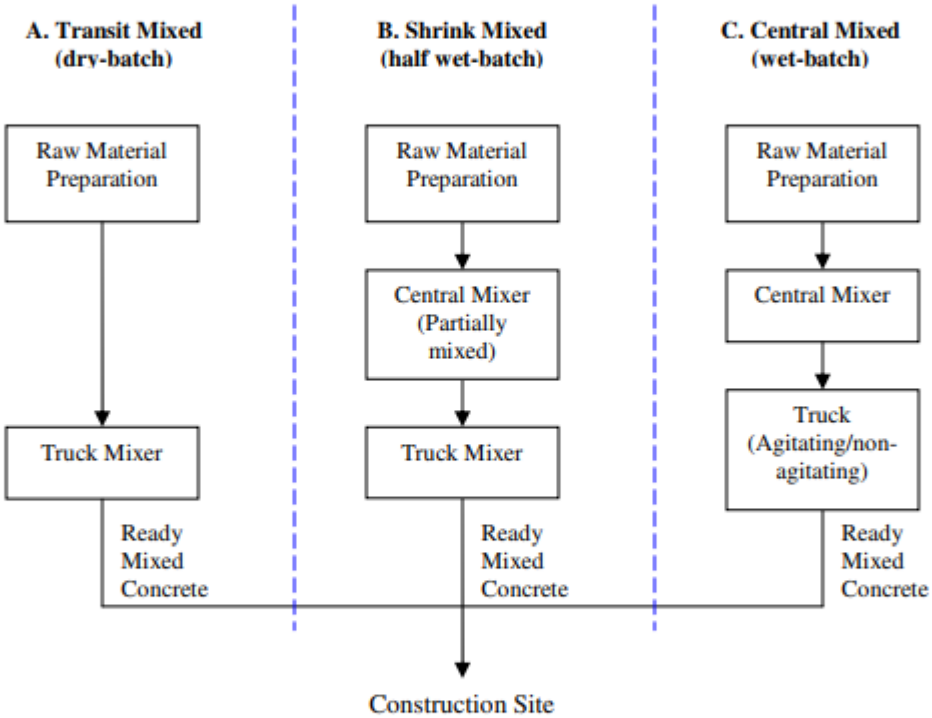

Figure 1: Types of RMC based on mixing methods. Source: Kermeli *et al.* (2013).

2.2. Quality Management of RMC

The accurate evaluation of the quality of RMC, which is presently the primary material used in construction, land development, and architecture, has a significant influence on ensuring that each stage of the production process is operating effectively and efficiently (Skrzypczak *et al*., 2021). Because RMC is normally produced in huge volumes for different uses, a tight quality management scheme should be adhered to bearing in mind the following: Material selection and storage, quality monitoring of materials, maintenance of the plant, equipment calibration, sampling of freshly made concrete, testing of RMC and analysis of test results, weight checking of loaded and unloaded trucks, material stock control and correction of reported faults and defects (Dhayanandhan and Sasikumar, 2017).

Quality control (QC) involves overseeing the characteristics of a product related to its quality, evaluating them against predetermined criteria or specifications, and implementing appropriate measures if any discrepancies arise from the established norms (Putri *et al.*, 2019). Dhayanandhan and Sasikumar (2017) described Quality control as a thorough and systematic evaluation of all aspects of the production process, starting from the procurement of materials and extending to the final delivery of the product at the designated location, to ensure that each stage of production complies with established quality standards. Effective quality control of concrete not only ensures the proper functioning of each stage of the production process but also directly affects the certification associated with factory production control as it serves as the foundation for ensuring that the production facility meets at least the necessary requirements (Skrzypczak *et al*., 2021). In line with Dhayanandhan and Sasikumar, (2017), Suryakanta (2018) and Naiknavare *et al.*, (2018), the quality control of RMC may be broken down into three parts: forward control, immediate control and retrospective control.

- Forward control is primarily concerned with the procurement of high-quality materials, their appropriate storage, quality monitoring of materials, modification of concrete mix design, calibration of equipment and maintenance of batching plant and transit mixers.
- Immediate control entails taking quick action to monitor concrete quality during

production and delivery. This includes accurate batch data reading, precise weighing, visual observation and testing of concrete during production and delivery, with an emphasis on assessing uniformity, cohesion, and workability, adjustment of water content, and finally making the necessary modifications at the plant either automatically or manually to batched quantities to account for observed, measured, or reported changes in materials or concrete qualities.

- Retrospective control primarily focuses on the procedures and processes used for quality control after concrete production. These include concrete sampling, testing, and result monitoring; truck weight checks at weighbridges; material stock control; and the identification and correction of faults.

Quality assurance (QA) on the other hand can be described as a set of pre-planned measures and organised efforts that are essential in ensuring that a product or service meets the specified quality requirements and provides sufficient assurance of its effectiveness (Achiso, 2021). Melesse, (2021) adds that the purpose of QA is to confirm that the processes, procedures, tools, and precautions in place are both present and effective, ensuring that the desired quality levels are achieved and that the resulting outcomes are of high quality. QA of RMC involves the inclusion of a quality control plan that provides a comprehensive outline of the frequency and type of inspection, testing, and sampling required to measure and regulate the different properties controlled by agency specifications (Achiso, 2021).

2.3. RMC Testing

To ensure that the quality of the concrete delivered to the customer meets the mix design specifications, RMC producers monitor the strength of their product on a daily, weekly, or monthly basis (Mohamed, 2012). According to Hossain & Rahman (2013), there are three commonly used strength tests for RMC, which include the slump test, compressive strength test, and split tensile test.

2.3.1. Slump Test

Slump testing can be viewed as a measurement of a concrete mix's resistance to shearing as it flows under its own weight (Andayani and Madenda, 2016). The most popular technique used to evaluate fresh concrete's flow characteristics such as consistency, flowability, pumpability, compactibility and workability is the slump test, which can conveniently be done on any site (Hoang and Pham, 2016; Mohan and John, 2020). The amount of time and concrete needed, the ease of operation, and the accessibility of the experimental structure all contribute to the widespread use of the slump test (Su et al., 2021). Concrete slump ranges in various applications are outlined in Table 1.

Table 1: Concrete slump ranges in various applications

Concrete mix type	Slump range (mm)	Application
Very dry	0 - 25	Road construction.
Low workability	10 - 40	Foundation with light reinforcement.
Medium workability	50 - 90	Normal reinforced concrete with little vibration.
High workability	> 100	Normal reinforced concrete

Source: Suvash, (2011).

During the slump test, three different types of slump could transpire: a true slump which refers to a uniform drop of the concrete mass without disintegration, a shear slump which donates a concrete mix that lacks cohesiveness and may segregate and bleed negatively affecting the concrete's durability and lastly, a collapse slump indicates that a concrete mix is excessively wet (Singh, 2010). Figure 2 graphically presents the 3 types of slumps:

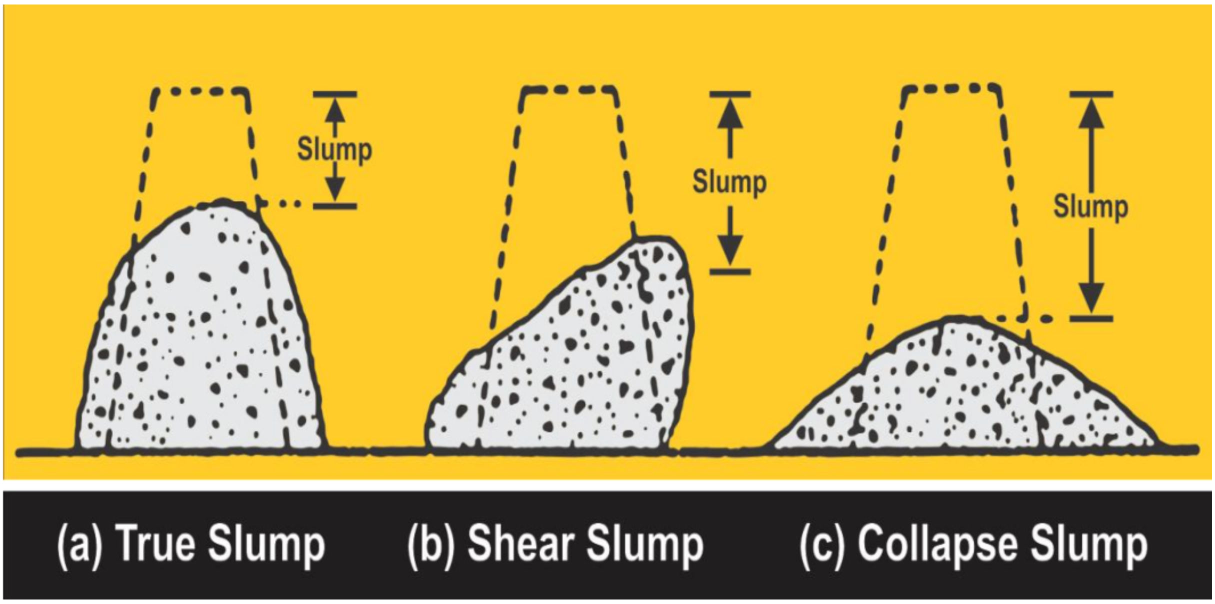

Figure 2: Types of Concrete Slump. Source: (Neville and Brooks (2010).

2.3.2. Compressive test

To meet the design specifications of a structure, concrete mixtures can be designed to have a wide range of mechanical and durability characteristics (NRMCA, 2014). Because it is the primary determinant of concrete quality, Engineers frequently consider the concrete's compressive strength as a performance factor when designing structures (NRMCA, 2014; Hassoun and Al-Manaseer, 2015). This compressive strength of concrete is measured using the compressive strength test which is used to evaluate the strength of hardened concrete and demonstrates its measure of resistance (Kumar and Tegar, 2018).

2.3.3. Split Tensile Test

Concrete cannot withstand extremely high tensile stresses because of its brittleness, which is crucial when considering cracking, shear, and torsional issues (Hassoun and Al-Manaseer, 2015). Due to small misalignment and stress concentrations in the gripping devices, direct tension testing is unreliable in estimating the tensile strength of concrete. Therefore, an indirect test commonly known as the Brazilian test, in the form of splitting a 150 x 300mm concrete cylinder, is widely used (Denneman *et al.*, 2011; Hassoun and Al-Manaseer, 2015). However, Denneman *et al.* (2011) point out that when compared to a direct tension test, the splitting tensile test has its drawback of not providing adequate information on the material's post-crack behaviour but only measures the tensile strength.

2.4. Cement and Concrete Production In Zambia

Fourteen (14) cement manufacturing companies in Zambia of which eight (8) are in the capital city have played a significant role in economic growth by providing easy access to cement for property developers. However, only three of them - Dangote Quarries Zambia Limited, Lafarge Cement, and Zambezi Portland Cement, have emerged as the primary contributors to the construction sector, producing a total of 1,956,519 metric tonnes of cement in 2016 (Tembo, 2017). Since the 2000s, the cement sector in Zambia has experienced substantial growth, with output increasing from approximately 340,614 tonnes in 2000 to more than 1,500,000 tonnes in 2012, as a result of sustained high demand for residential, commercial, and public infrastructure projects throughout the country (UNCTAD, 2020).

Quality management of cement and concrete products in Zambia is mainly managed by the Zambia Bureau of Standards (ZABS), in collaboration with diverse stakeholders such as government departments, industry representatives, academic institutions, regulators, consumer associations, and non-governmental organisations, through the development and implementation of two standards, namely ZS - 802 and ZS - 803. These standards are responsible for regulating the nationwide testing and sampling procedures for concrete (ZABS, 2013a; ZABS, 2013b).

Standardisation plays a crucial role in the construction sector for various reasons. It minimises the necessity for extensive on-site inventory, facilitates effective communication regarding materials, enables comprehensive inventory analysis, strengthens quality control measures by precisely outlining requirements, and simplifies the identification of dependable suppliers through the adoption of national standards (Achiso, 2021). Both legal mandates and industry norms establish well-defined testing protocols and quality assurance standards that cover every stage of the production process of RMC, including its delivery to construction sites and these guidelines emphasise the importance of adhering to technical specifications to ensure the efficient execution and successful completion of construction projects (Skrzypczak et al., 2021). In this regard, ZABS, a specialised organisation dedicated to standardisation, quality assurance, metrology, and testing offers training and advisory services in quality management, provides expertise in quality assurance and quality control, and develops implementation schemes for various industries like construction. Furthermore, ZABS facilitates material examination and testing by organising suitable facilities (ISO, 2022).

3. Research Methodology

3.1. Research Approach and Design

This study employed a mixed-method approach enhancing the conclusiveness, precision and reliability of findings by integrating two different methods in a manner that leverages the advantages of qualitative methods to compensate for the limitations of quantitative methods, and vice versa (Plano and Ivankova 2016; Dawadi et al., 2021). Furthermore, this study adopted a parallel convergent mixed-methods research design. In a convergent design, combining both datasets allows researchers to achieve a comprehensive understanding that surpasses what can be obtained from either quantitative or qualitative results alone (Dawadi et al., 2021). Therefore, the design allowed for a comprehensive examination of the existing guidelines, the role of regulatory bodies and an investigation of the quality control and assurance practices in the RMC industry in Zambia considering both numerical data and in-depth insights from key stakeholders.

3.2. Population and Sampling Technique

The targeted population comprised seven out of eight RMC plants found in Lusaka, selected through a non-probability purposive sampling technique to obtain the most valuable information for the study. The study also included key industry regulatory bodies namely the Engineering Institution of Zambia (EIZ), the National Council for Construction (NCC), the Zambia Bureau of Standards (ZABS), and the Zambia Compulsory Standards Agency (ZCSA).

3.3. Data Collection and Analysis

Qualitative data was obtained through desk study and semi-structured interviews. Document analysis of existing RMC quality management guidelines was carried out followed by semi-structured interviews which were conducted with key personnel from different regulatory bodies to gain insight into their unique role and involvement in the quality management of RMC production in Zambia.

Quantitative data on the other hand was acquired through an observation checklist. Direct observation as a data collection technique to assess the quality control and quality assurance practices of the Zambian RMC industry was preferred. According to Kawulich (2012), direct observation entails the act of carefully watching and examining objects or individuals in a specific environment without actively engaging or interacting with them. All three aspects of quality control namely forward control, immediate control and retrospective control were observed. Under forward control, material storage, quality monitoring and inspection, and calibration and maintenance of plant equipment were observed. concrete sampling process, testing procedures and non-conformance management were the immediate control aspects that were closely observed. Lastly, concrete sampling and testing post-production, truck weight checks, delivery time tracking and concrete slump testing on site upon delivery were observed as part of the retrospective control. With regards to quality assurance, aspects ranging from documentation and procedure, and raw material inspection to batching and mixing processes were observed.

The quantitative data collected from the observation checklist at the targeted RMC plants was analysed using Excel statistical software. Descriptive statistics, such as means, frequencies, and percentages, were calculated to evaluate general quality management in RMC production in Zambia.

3.4. Limitations of the Study

Acknowledging the Hawthorne effect in this study is essential since the behaviour of workers in the observed RMC plants might have deviated from their typical tendencies owing to the awareness of being observed, potentially influencing the outcomes of the study. Additionally, it is crucial to recognise the possibility of biases in the collected data, as stakeholders from regulatory bodies interviewed might have provided information that reflects positively on their organisation.

3.5. Ethical Considerations

Ethical approval from the University of Zambia Ethics Committee known as the Natural and Applied Sciences Research Ethics Committee (NASREC) was obtained. All information gathered during the study was used solely for academic purposes and confidentiality was maintained. Voluntary participation of all participants was emphasised too.

4. Results and Discussion

4.1. Existing Guidelines on Quality Management of RMC

The study identified the existing standards employed in Zambia for the quality management of RMC as shown in Table 2.

Table 2: Existing guidelines on quality management of RMC in Zambia.

Standards No.	Standards Name	Standard Scope
C94/C94M - 17a	Standard Specification for Ready-Mixed Concrete	The specification pertains to freshly mixed and unhardened ready-mixed concrete delivered to a buyer as per the specified conditions.
ZS ASTM C39	Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens	The specification outlines the method for assessing the compressive strength of cylindrical concrete specimens, encompassing both moulded cylinders and drilled cores.
ZS ASTM C33	Standard Specification for Concrete Aggregates	The specification outlines the criteria for grading and quality of fine and coarse aggregate intended for utilisation in concrete.
ZS 802 - 1	Concrete Tests Part 1: Mixing Fresh Concrete in the Laboratory	The Standard provides guidelines for accurately batching and mixing concrete in controlled laboratory conditions for quality assessment and practical application on construction sites.
ZS 803 - 2	Concrete Tests Part 2: Sampling Of Freshly Mixed Concrete	The standard outlines the procedures for obtaining samples of fresh concrete, whether on-site or in a laboratory, and describes the subsequent testing methods used to determine if the concrete meets the criteria set by the relevant standard(s).
ZS EN 197	Cement Part 1: Composition, Specifications and Conformity Criteria for Common Cements	The standard offers clear and specific definitions for the constituents of cement and outlines their mechanical, physical, and chemical prerequisites. Additionally, it establishes criteria for conformity and sets forth durability requirements.
ZS EN 197	Cement - Part 2: Assessment and verification of constancy of performance	The standard specifies the scheme for the assessment and verification of constancy of performance (AVCP) of cements, including certification of constancy of performance.
ZS EN 196	Methods of testing cement - Part 1: Determination of strength	The standard outlines the procedure for determining the compressive strength of cement mortar and, if desired, the flexural strength as well.
ZS EN 196	Method of testing cement - Part 2: Chemical analysis of cement	The standard specifies the methods for the chemical analysis of cement.

4.2. The Role of Regulatory Bodies

4.2.1 Engineering Institution of Zambia (EIZ)

The interview established the role and mandate of EIZ as stipulated in the Engineering Institution of Zambia Act of 2010. Concerning the quality management of RMC in Zambia, the institution is mandated to register both individuals and corporate organisations and units engaged in RMC production. Responded A said, *''We as EIZ are mandated to offer quality assurance by ensuring engineering organisations and units are registered and that their workforce is also registered to practise engineering in Zambia.''* Additionally, it was confirmed that the Institution conducts unannounced visits to different RMC plants quarterly to verify the compliance of both companies and their workforce. When such surprise inspections reveal any discrepancies, the non-compliant company or individual is subjected to the relevant provisions in sections 18 and 15 of the EIZ Act respectively.

4.2.2 National Council for Construction (NCC)

During the interview, it was revealed that according to the National Council for Construction Act No. 10 of 2020, NCC has been assigned the responsibility of registering and regulating the supply of building materials, including ready-mix concrete. As part of its regulatory role, NCC conducts regular quality control checks on concrete works at random construction projects throughout the country. Furthermore, NCC allocates funds to a joint committee with the Zambia Bureau of Standards (ZABS) to adopt, adapt, or update all construction-related standards, including those pertaining to concrete and its components. On the other hand, the council is also supposed to inspect production plants and the sites where various building materials are sourced. However, two of the three respondents (66%) from NCC reported that due to financial constraints and a delay in receiving a Statutory Instrument (SI) from the parent Ministry, that would strengthen their enforcement capabilities, no inspections are currently being carried out. Respondent B stated, "*Inspecting production sites of building materials, whether on construction sites or company premises, is within our mandate, but insufficient funding prevents us from doing so.*" Respondent C added, "*We are facing challenges in fully implementing the registration and regulation of suppliers of building materials, mainly because of an SI pending approval at the ministry for the past 4 years or so*."

4.2.3 Zambia Bureau of Standards (ZABS)

ZABS plays a crucial role in managing the quality of Ready-Mix Concrete (RMC) by evaluating RMC and cement suppliers' production systems against internationally recognized standards. Additionally, ZABS has the authority to grant voluntary licences and trademarks to suppliers of different cement and RMC brands, serving as a quality indicator for customers. Once annually, ZABS conducts surprise inspections on cement suppliers, examining cement's chemical composition, flexural and compressive strength of specimens, as well as storage and transportation practices to the market. Furthermore, market surveillance surveys are carried out in response to customer complaints, and in such cases, ZABS inspects the affected brand multiple times within the year. If any supplier is found to be non-compliant, a Non-Conformity Report (NCR) is issued and 60 days is given to rectify the non-compliance, failing to which their licence is revoked by ZABS.

4.2.4 Zambia Compulsory Standards Agency (ZCSA)

In the Zambian construction industry, ZCSA plays a crucial role in managing the quality of Ready-Mix Concrete (RMC) supplied. Their responsibility involves conducting mandatory quality control inspections at cement production facilities. These inspections occur quarterly for each facility, and only those meeting internationally acceptable standards are granted permits to supply the market. However, facilities found non-compliant with these standards face repercussions. Non-compliance falls into three categories: critical, which results in a complete shutdown of plant production, major, and minor. The latter two categories offer the facilities an opportunity to rectify the identified issues within a month.

4.3. Quality Control and Quality Assurance Practices

Quality control (QC) and quality assurance (QA) procedures from seven (7) out of eight (8) RMC plants in Lusaka were observed and documented.

4.3.1 Quality Control

This study examined three dimensions of quality control: forward control, immediate control, and retrospective control. The results of the observation shows that **d**uring the forward control assessment, the proper storage and labelling of the concrete components, including fine and coarse aggregates, cement, water, and admixtures, were considered as the proactive control measures. Among all the plants observed, two (28.6%) exhibited correct storage and labelling for fine aggregates and an equal percentage for coarse aggregates. For cement, this figure was three (42.9%), while for water, it was one (14.3%). Remarkably, all seven plants (100%) demonstrated proper storage and labelling of admixtures. The results are summarised in Figure 3:

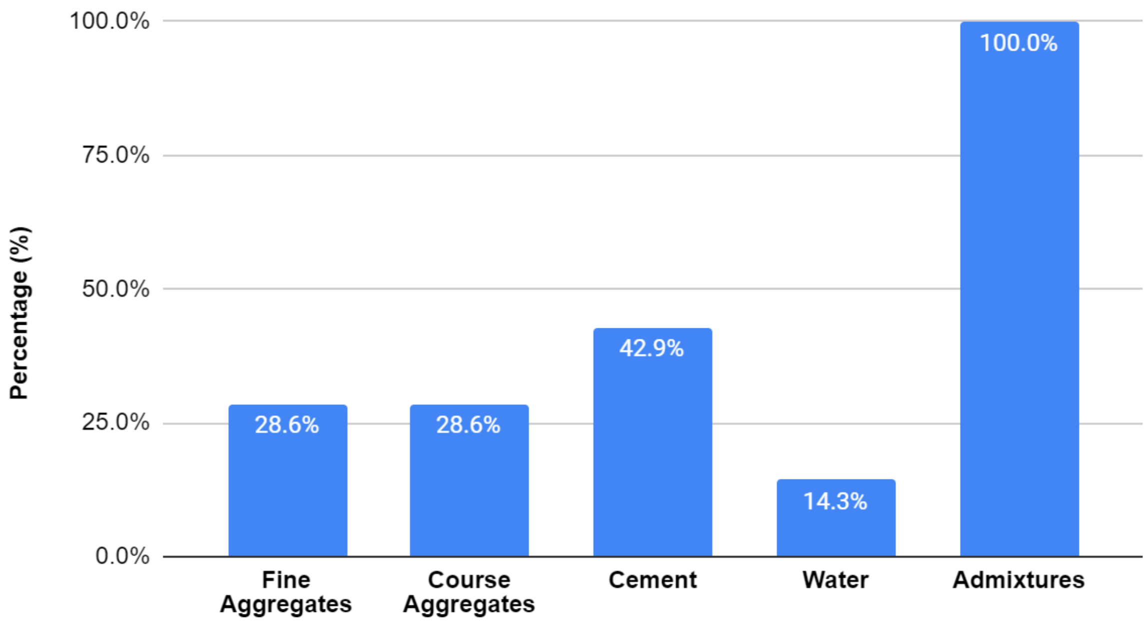

Figure 3: Forward control of raw material storage.

Additionally, regular calibration of RMC plant equipment was also observed as part of the forward control assessment. Among all plants, five (71.4%) regularly calibrated their equipment while two (28.6%) did not. Figure 4 depicts a summary of the results.

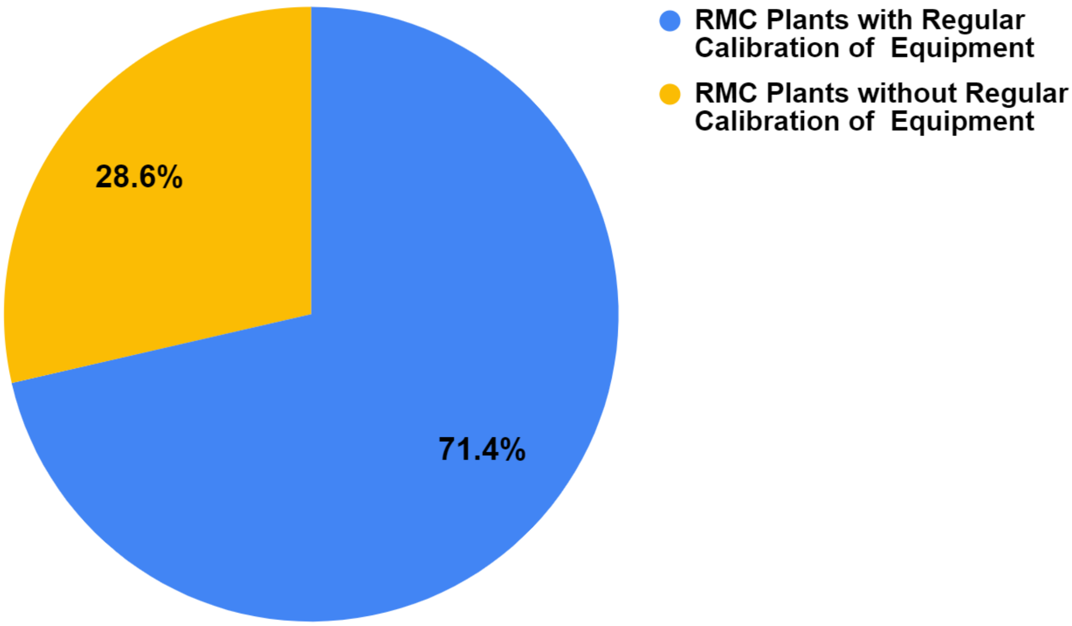

Figure 4: Forward control - calibration of RMC plant equipment.

Under the assessment of immediate control, the observation of concrete sampling, testing, and non-compliance management took place. The findings revealed that out of the total RMC plants surveyed, merely two (28.6%) had implemented a sampling plan, three (42.9%) followed regular sampling intervals, and four (57.1%) appropriately labelled their concrete samples before storage. Additionally, it was observed that only two (28.6%) of the plants had a non-compliance management system in place, one (14.3%) had a procedure for investigating non-compliance, and two (28.6%) had formulated corrective action plans. On a positive note, a majority of plants, six (85.7%), had well-established procedures for testing concrete workability. Figure 5 summarises these findings.

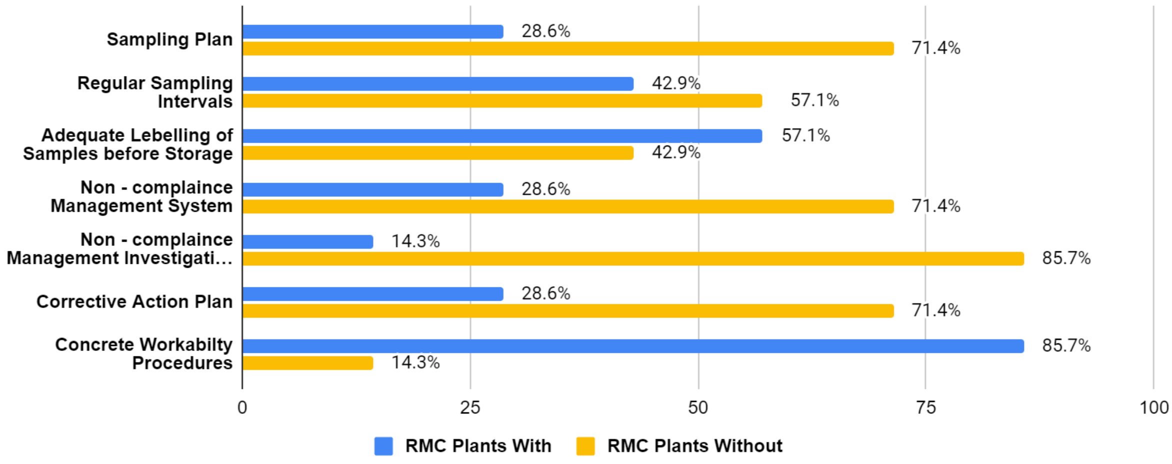

Figure 5: Immediate control - concrete sampling, testing and non-compliance management.

Several aspects were observed while evaluating retrospective control in various RMC plants. These aspects included examining whether concrete tests such as the compressive strength test, slip tensile test and on-site simple test were being carried out. It was observed that each of the RMC facilities conducted compressive strength tests in their laboratories. On the other hand, only two (28.6%) of them carried out slip tensile tests, while five (71.4%) conducted on-site slump tests, even when not specifically requested by clients. Furthermore, the observation also involved monitoring truck weight checking and concrete delivery times. The findings indicate that among all observed RMC plants, four (57.1%) performed truck weight checks while three (42.9%) kept track of the delivery time for concrete to their respective customers. A summarised representation of these findings can be found in Figure 6 below:

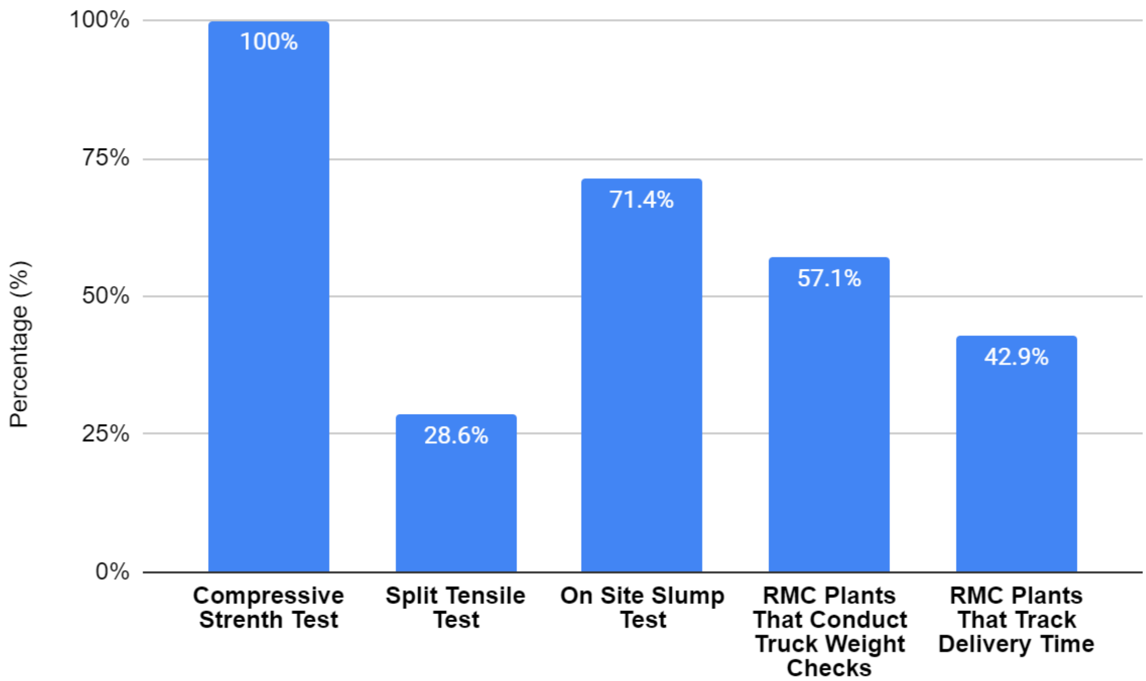

Figure 6: Retrospective control - concrete testing, truck weight checks and delivery Time tracking.

4.3.2 Quality Assurance

The three main aspects of quality assurance that were observed included documentation of QA Standard Operating Procedures (SOPs), quality monitoring and inspection of raw materials, and evaluation of batching and mixing equipment of the various RMC plants. The findings are outlined below:

With regards to the documentation of standard operating procedures, out of the RMC plants under observation, the majority, six (85.7%) of them, had well-defined QA standard operating procedures documented, while a minority, only one (14.3%), lacked any such documentation. Figure 7 provides a visual representation of these findings.

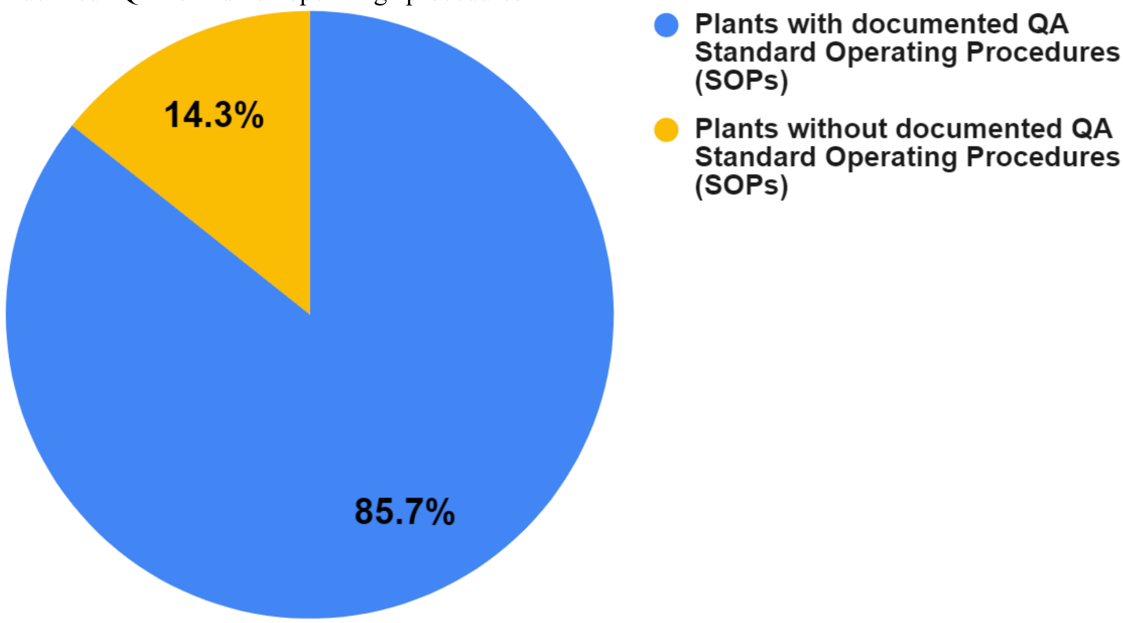

Figure 7: Documentation of QA standard operating procedures.

Regarding the monitoring and inspection of the quality of raw materials, findings revealed that two (28.6%) of the plants monitored and inspected the quality of fine aggregates, while three (42.9%) performed the same for coarse aggregates. Additionally, five (71.4%) of the plants inspected and monitored the quality of cement while two (28.6%) carried out quality checks on water. Remarkably, six (85.7%) monitored the quality of admixtures. A summary of these findings is illustrated in Figure 8.

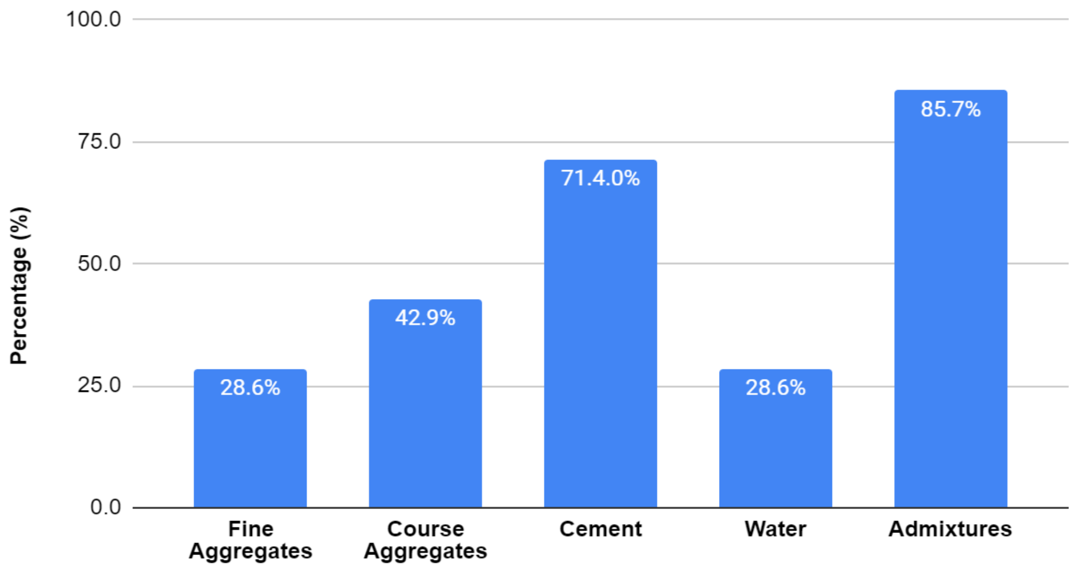

Figure 8: Quality monitoring and inspection of raw materials.

In the production of high-quality concrete, the processes of batching and mixing play a vital role. Among the RMC plants studied it was found that, as shown in Figure 9, two (28.6%) plants had established SOPs for batching and mixing, while three (42.9%) plants utilised modern weighing systems in their operations.

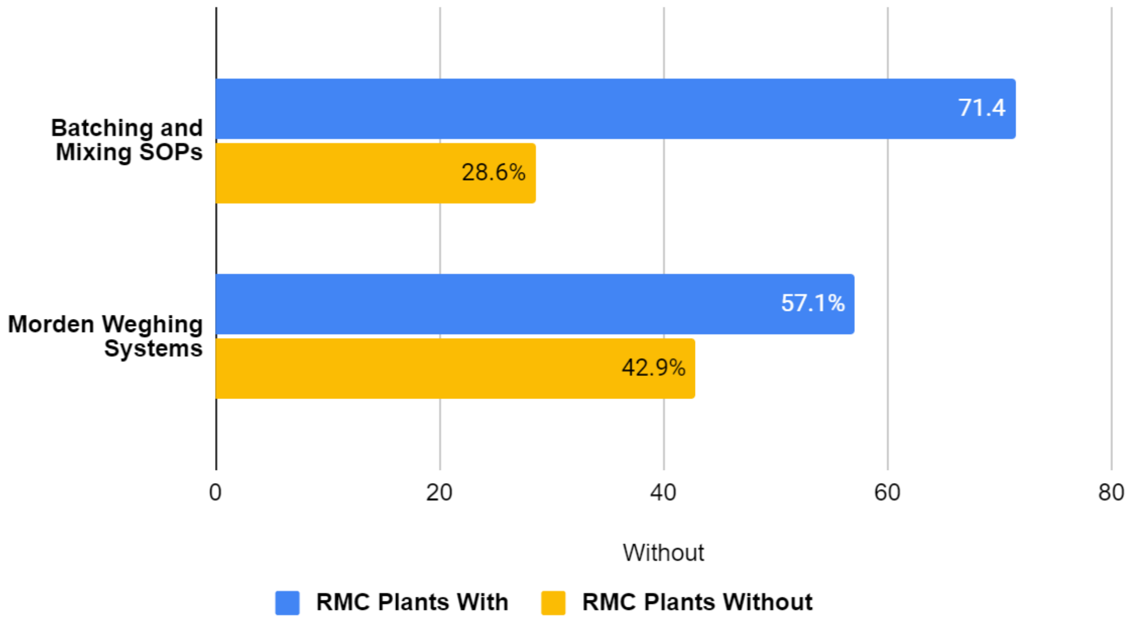

Figure 9: RMC batching and mixing.

5.Discussion

5.1. Existing Guidelines

Despite the existence of established standards and guidelines, some of which have been adopted from globally recognised standards, there is an essential requirement for effective implementation to guarantee the proficient management of RMC quality. Regrettably, within Zambia's regulatory framework, only ZS EN 196 and ZS EN 197 are mandatory, and these exclusively relate to cement, which is just one of the raw components necessary for RMC production. This selective application of guidelines raises questions regarding the potential implications for overall RMC quality. The absence of compulsory adherence to guidelines for crucial concrete components could create variations in the quality of the final product. This variability might arise due to differential interpretations of quality requirements, resulting in a lack of standardised practices across the industry. Another challenge faced by African standardisation bodies as noted by Schmidt et al. (2023) is the lack of increased awareness of relevant parameters affecting the sustainability of the adopted standards. This is evident in the Zambian setup where most of the standards were simply adopted with little or in some cases no adequate review to accommodate more local attributes and parameters to the standards.

5.2. The Role of Regulatory Bodies

Regulatory bodies are pivotal in promoting public safety and quality in the construction industry (Zakharoff, 2023). Notably, it was found that regulatory bodies such as EIZ, NCC, ZABS, and ZCSA have clearly defined mandates and roles concerning the management of RMC quality in Zambia. However, executing these mandates and roles has been inadequate due to the absence of a sense of responsibility. This has resulted in RMC producers operating rather independently, with minimal engagement from these regulatory bodies. As Achiso (2021) pointed out, the concrete industry suffers from regulatory bodies not effectively fulfilling their designated duties, primarily due to a lack of accountability. Additionally, another obstacle confronting regulatory bodies in the African concrete sector in their quest for effective quality control is the absence of enforceable standards, coupled with inadequate surveillance systems, leaving room for potential safety hazards such as building collapses to occur without proper oversight (Schmidt *et al*., 2018). Due to the absence of strict and enforceable standards within the Zambian RMC space, the regulatory bodies risk becoming redundant in overseeing RMC quality management.

5.3. QC and QA Practices

Variations observed in both QC and QA practices in the Zambian RMC industry risk the supply of concrete to the market of inconsistent quality. Issues such as effective storage of raw materials enhance plant productivity, the overall operational efficiency, and contribute to improved quality (Achiso, 2021). As noted, Zambian producers of RMC must prioritise the appropriate storage of essential raw materials, aggregates, cement, and water. Additionally, according to Hossain and Rahman (2013), the absence of regular calibration for batching plants has a notable effect on the quality of produced RMC. It's praiseworthy that most RMC plants in Zambia are presently conducting routine equipment calibration. Nevertheless, the remaining minority must do the same to enhance the overall management of RMC quality.

6. Conclusions

The study has unveiled a landscape in which guidelines governing the quality management of RMC in Zambia exist, though with notable gaps in mandatory adherence. While standards such as ZS EN 196 and ZS EN 197 regarding cement are obligatory, crucial guidelines concerning other concrete components like fine aggregates, coarse aggregates, water, and admixtures remain optional, granting RMC producers discretionary control over their utilisation.

In terms of industry regulatory oversight, the roles of bodies like EIZ, NCC, ZABS, and ZCSA collectively aim to uphold RMC quality standards. However, the study reveals challenges stemming from inconsistent execution and a lack of coordination, attributed partly to a sense of irresponsibility and constrained funding.

The study also looked into quality control in Zambia's RMC industry. Forward control assessments show that 71.4% of plants engage in equipment calibration, but also reveal differences in storage and labelling adherence. Immediate control aspects indicate mixed implementation levels, pointing out areas like sampling plans and non-compliance management that need improvement. Retrospective control assessments demonstrate a commitment to strength tests but suggest enhancing practices such as split tensile tests. Concerning quality assurance, the study concluded that a significant number of RMC facilities meticulously record QA standard operating procedures, thereby conforming to industry standards and ensuring consistent and reliable RMC production. Additionally, a substantial majority of RMC plants conduct thorough quality inspections of their raw materials. However, the study uncovers a concerning aspect: a portion of the plants lacks standard operating procedures for batching and mixing, compounded by a limited adoption of modern weighing systems.

7. Recommendations

To enhance the management of RMC quality in Zambia, the following are the recommendations.

- **Industry Collaboration for Best Practices:** There is a need to establish an industry association that brings together RMC producers, regulatory bodies, experts, and academia to collaborate on setting and updating industry best practices regularly.
- **Enhancing Standardisation of Practices:** With help from the establishment of an industry association, there should be an effort to strengthen and impose standardised practices.
- **Quality Audits:** The government through industry regulatory bodies should consider conducting periodic third-party quality audits on RMC plants to assess their adherence to established standards and procedures.
- **Compulsory RMC Standards:** It is essential to consider establishing C94/C94M - 17a - Standard Specification for Ready-Mixed Concrete as a mandatory industry standard to ensure consistent adherence to globally recognised concrete quality standards.

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