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Analysis of the Impact of Key Points in Quality Inspection and Control of Incoming Raw Materials on the Molding Quality of Cement Concrete Pavement Construction

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Abstract: Based on the fundamental background of a cement concrete pavement construction project for a highway engineering endeavor, this paper delves into the impact of key points in quality control for incoming raw materials on the molding quality of the pavement during construction. It encompasses the effects of incoming inspections on cement, aggregates, admixtures, and mineral admixtures on the subsequent molding quality of the pavement. Additionally, targeted optimization suggestions are proposed based on various impacts. The aim is to provide valuable references for controlling the quality of raw materials and the molding effects of pavements in similar future projects.

Keywords: Cement concrete pavement; Raw materials; Incoming quality inspection; Molding quality

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1. Preface

Cement concrete pavements offer numerous advantages, including high strength, durability, and long service life, and have been widely applied in modern highway and municipal road construction. Their molding quality directly influences road service life and traffic safety. As the most fundamental material in cement concrete pavement construction, the quality control of raw materials is crucial for ensuring molding quality. Therefore, engineering units must place sufficient emphasis on the quality inspection of incoming raw materials, clarify the primary impacts of key control points on the subsequent molding quality of pavement construction, and thereby reasonably control pavement molding quality through incoming quality sampling inspection and control methods.

2. Project background

A municipal road mainline renovation project spans 8.6 km with a pavement width of 24 m and a designed speed of 60 km/h. The construction requires the application of a cement concrete rigid pavement structure, with a concrete strength design of C35, requiring a flexural strength of no less than 4.5 MPa, and a designed service life of 15 years. Since the project section passes through farmland areas, industrial parks, and residential areas, it experiences heavy traffic flow and is significantly affected by the rainy season. Therefore, high requirements are placed on the pavement's strength, smoothness, impermeability, and wear resistance during construction. A large amount of cement, aggregates, admixtures, and mineral admixtures will be used during construction, with various raw materials sourced from a wide range of suppliers, resulting in significant differences in product quality. Additionally, some raw materials may be contaminated or dampened during transportation. Given the tight project schedule, large batches and high frequencies of incoming raw materials, higher demands are placed on quality inspection and control. To ensure the molding quality of pavement construction, engineering units need to analyze the key points of quality control for incoming raw materials and their impact on the molding quality of pavement construction.

3. Key points in quality control for incoming raw materials

3.1. Inspection and control of incoming cement

In cement concrete mixtures, cement serves as the core binding material, and its quality directly determines the strength and durability of the concrete. According to engineering design standards, ordinary Portland cement should be used for this project. Upon arrival, engineering units should first strictly verify relevant documents such as supplier qualifications, factory inspection reports, and product certificates to ensure that the cement variety, production batch, and strength grade meet design requirements, promptly returning any cement materials that do not comply with design standards. During inspection, engineering units should strictly follow design requirements to conduct batch sampling and send for inspection, focusing on checking indicators such as cement fineness, mortar strength, soundness, and initial and final setting times to ensure that they meet design standards. Unqualified materials should be strictly prohibited from entering the site. Meanwhile, cement from different manufacturers and batches should be stored separately, with storage time controlled at three months or less, and rain and moisture protection measures should be taken to ensure cement stability [1]. **Table 1** outlines the key indicator control requirements for cement incoming inspection for this project.

Table 1. Key indicator control requirements for cement incoming inspection for this project

No.	Indicator	Control requirement
1	Fineness (Specific Surface Area) (m^2/kg)	300-350
2	3d flexural strength (MPa)	≥ 3.5
3	28d flexural strength (MPa)	≥ 4.5
4	Initial setting time (min)	≥ 45
5	Final setting time (h)	≤ 10

3.2. Inspection and control of aggregate mobilization

Cement concrete aggregate mainly consists of coarse aggregate and fine aggregate, whose quality plays a decisive role in the strength, compactness, and workability of the mixture. The coarse aggregate selected for this project is continuous graded crushed stone ranging from 5–31.5 mm. Upon mobilization, strict quality inspections must be conducted in accordance with design requirements to ensure that the crushing index does not exceed 15%, the mud content does not surpass 1.0%, the content of flaky and elongated particles is controlled at 15% or below, the compressive strength of the parent rock reaches 80 MPa or above, and there are no impurities or weathering. Natural medium sand is chosen as the fine aggregate, requiring a fineness modulus of 2.3–3.0, a mud content not exceeding 3.0%, a clay lump content not exceeding 0.5%, a mica content controlled at 2.0% or below, and the colorimetric test for organic matter content must meet design standards. According to the engineering design requirements, all materials arriving on site should undergo batch sampling inspections, and unqualified aggregate should be promptly removed from the site. Additionally, the mobilized aggregate should be stacked separately to prevent contamination or mixed stacking [2].

3.3. Inspection and control of admixture and mineral admixture mobilization

Admixtures are crucial materials that ensure the strength, workability, and durability of cement concrete. In this project, the selected admixture is a polycarboxylate-based high-efficiency water reducer. Upon mobilization, strict verification of its factory inspection report and product qualification certificate should be conducted in accordance with engineering design requirements to ensure that key indicators such as setting time and water reduction rate comply with design specifications and that it exhibits good compatibility with cement. Simultaneously, batch sampling tests should be conducted to inspect key indicators such as bleeding rate, air content, and water reduction rate. Only after confirmation of qualification can mobilization be permitted; otherwise, its use is strictly prohibited. The selected mineral admixture is Class I fly ash, which should undergo strict batch sampling inspections in accordance with design standards upon mobilization, with the water ratio controlled at 95% or below and the ignition loss controlled at 8% or below. Unqualified materials are strictly prohibited from entering the site for use [3]. Both the mobilized admixtures and mineral admixtures should be properly labeled and stored separately.

4. The main impacts of quality control over incoming raw materials on the forming quality of cement concrete pavement construction

4.1. The impact of cement testing and control on construction forming quality

In the construction of cement concrete pavements, the strength and crack resistance are directly influenced by the quality of the cement. If strict testing and control measures are not implemented upon arrival, allowing substandard cement to be used in construction, a series of quality issues may arise. If the fineness of the cement exceeds standards, the rate of hydration reaction in the cement concrete mixture will accelerate, further shortening the initial setting time of the concrete. This can easily lead to rapid slump loss or poor vibration compactness during construction, resulting in quality issues such as honeycombing and pitting on the pavement surface. If the soundness of the cement does not meet design standards, uneven volume shrinkage is likely to occur during the concrete hardening process, leading to the formation of through-cracks on the pavement at any time, which seriously affects the integrity and service life of the pavement. If the strength grade of the cement is insufficient, the compressive and flexural strengths of the pavement will not meet design requirements, leading to issues such as spalling, sanding, or slab breakage during use, significantly reducing the pavement's load-bearing capacity. During the incoming inspection of raw materials for this project, the engineering unit discovered a batch of damp cement. After testing, it was found that the 3-day flexural strength of the damp cement mortar was only 3.2 MPa, failing to meet engineering design requirements. Upon discovery, the engineering unit promptly returned this batch of cement raw materials and prevented their use, effectively avoiding issues of insufficient strength in the formed pavement.

4.2. The impact of aggregate testing and control on construction forming quality

As the framework of the cement concrete mixture for highway pavements, key indicators of aggregates such as particle size distribution, silt content, and crushing value must undergo strict testing before arrival. The effectiveness of control over these incoming inspection indicators will directly impact the subsequent compactness, strength, and workability of the concrete mixture. If the particle size distribution of coarse aggregates does not meet design requirements and exhibits excessive void content, the amount of cement used will increase further, thereby increasing the risk of pavement cracking under the action of hydration heat. Moreover, achieving good control over compactness after vibration becomes difficult, easily leading to the formation of pores within the pavement, reducing its wear resistance and impermeability, and making it more prone to quality issues such as sanding and water seepage during subsequent practical use [4]. If the silt content of coarse aggregates exceeds engineering design standards, the soil will envelop the aggregate surface, weakening the bond between cement paste and aggregates. This will further reduce the strength of the concrete mixture and increase its shrinkage, making the pavement more prone to cracking. Similarly, if the quality of fine aggregate incoming inspections is not effectively controlled, it can also significantly adversely affect the forming quality of pavement construction. If the fineness modulus of fine aggregates is too low and contains excessive fine sand, the amount of cement and water used in the concrete will increase further, leading to increased concrete shrinkage and easily triggering pavement cracking issues [5]. If the fineness modulus is too high and contains excessive coarse sand, the workability of the concrete will decrease, and vibration will become more difficult, ultimately resulting in quality defects such as pitting and honeycombing on the pavement surface. **Table 2** compares the basic impact parameters of silt content in coarse aggregates for cement concrete in this project on pavement strength and smoothness.

Table 2. Comparison of basic impact parameters of silt content in coarse aggregates for cement concrete in this project on pavement strength and smoothness

No.	Indicator	Clay content in coarse aggregate (%)		
		≤ 1	1.5–2.0	> 2.0
1	28d compressive strength of concrete (MPa)	38.6	34.2	29.8
2	28d flexural strength of concrete (MPa)	4.9	4.2	3.7
3	Pavement smoothness pass rate (%)	98.5	82.3	65.7

4.3. Impact of inspection and control of admixtures and mineral admixtures on construction molding quality

During the pavement construction process using cement concrete mixtures, proper control over the incoming inspection of admixtures and mineral admixtures can further improve the performance of the concrete, thereby ensuring that the pavement molding quality meets standards. Conversely, improper inspection and control of incoming admixtures and mineral admixtures can severely affect the final construction molding quality of the pavement [6]. If the water-reducing rate of the admixture is insufficient, it will increase the water consumption during the mixing process of the concrete mixture, further increasing the water-to-binder ratio of the mixture, reducing the concrete strength, and causing greater shrinkage of the concrete, which can easily lead to pavement cracking. If the admixture and cement do not have good compatibility, it will result in rapid loss of concrete slump, further increasing the difficulty of mixture paving and vibration, adversely affecting pavement smoothness, and making it prone to quality defects such as honeycombing and pitting. For mineral admixtures, if the incoming inspection control is unreasonable, resulting in excessive loss on ignition of fly ash and high residual carbon content, it will reduce the bond strength between cement paste and aggregates, thereby decreasing concrete strength. At the same time, it will further adsorb admixture molecules, causing abnormal loss of slump. If the fly ash has excessive moisture content, the actual water consumption during concrete mixing will further increase, exacerbating concrete shrinkage and easily leading to pavement cracking problems [7]. During the inspection of this project, a problem of poor compatibility between an admixture and cement was once discovered, resulting in a loss of more than 50% of the concrete slump within half an hour. By promptly replacing the admixture, the engineering unit effectively ensured the pavement molding quality.

5. Optimization suggestions for incoming inspection and control of raw materials based on ensuring the construction molding quality of cement concrete pavements

Based on the analysis of the impact of raw material selection and on-site quality inspection on pavement molding quality during cement concrete pavement construction in this project, to further ensure the construction molding quality of cement concrete pavements in actual construction, engineering units need to take the following measures to optimize the incoming inspection and control of raw materials [8]. Firstly, establish a stricter admission mechanism for raw material suppliers, strictly review their production qualifications, quality management systems, and historical cooperation performance, and prioritize suppliers with good reputation and stable quality. Additionally, comprehensively specify raw material quality standards and inspection requirements when signing supply contracts to control raw material quality from the source effectively. At the same time, regularly assess supplier qualifications to promptly identify and eliminate suppliers with unstable material quality, providing better guarantees for the supply quality of raw materials. Secondly, optimize the incoming inspection process for raw materials, arrange professional inspectors for inspection, and equip them with complete inspection equipment. Clearly define the inspection methods, frequency indicators, and acceptance criteria for various raw materials, and require inspectors to strictly implement sampling inspection according to regulations to ensure the authenticity and accuracy of on-site inspection results. At the same time, establish a comprehensive raw material inspection ledger to record detailed information such as incoming batches and inspection results of raw materials, ensuring full traceability of raw materials [9]. Thirdly, strictly inspect and manage the storage quality of raw materials, regularly review their actual storage conditions and quality and performance to control the stability of raw materials effectively. Fourthly, strengthen professional training for on-site inspectors and management personnel, comprehensively popularize quality inspection and control points for various raw materials, further improve the responsibility awareness and technical level of inspectors, and make inspection work more standardized and efficient. At the same time, establish a comprehensive raw material quality responsibility mechanism to clarify the relevant responsibilities of personnel in each position, avoiding situations such as dereliction of duty or misconduct by personnel during incoming inspection of raw materials, thereby ensuring good control over inspection work [10].

6. Conclusion

In summary, during the construction process of modern cement concrete pavements, scientific, reasonable, and strict incoming inspection and control of raw materials are key measures to ensure the quality and performance of raw materials, while also directly affecting the construction molding effect of pavements. Therefore, engineering units need first to clarify the key points of quality inspection and control and their impact on the subsequent construction molding quality of pavements, and then take reasonable measures to optimize the incoming inspection and control work of raw materials based on actual engineering conditions. This will further improve the incoming inspection quality of cement concrete raw materials, ensure the construction molding effect of cement concrete pavements, improve pavement performance, and extend pavement service life.

Disclosure statement

The authors declare no conflict of interest.

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