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# A Performance Study on Asphalt Concrete Mixes with Different Waste Materials as Modifiers in Pavement Application

**Abhijith R P[1], Freeda Christy[2], Renju C M[3], Simi M R[4]**

Research Scholar, Department of Civil Engineering, Kalasalingam Academy of Research and Education, Tamil Nadu, India[1]

Professor, Department of Civil Engineering, Kalasalingam Academy of Research and Education, Tamil Nadu, India[2]

Assistant Professor, Department of Civil Engineering, Marian Engineering College, Trivandrum, Kerala, India[3]

Associate Professor, Department of Civil Engineering, Mahaguru Institute of Technology, Kayamkulam, Kerala, India[4]

**ABSTRACT:** In order to study the influence of nano-MgO on the strength characteristics of cement-reinforced waste road recycled aggregate (CRA), the California bearing ratio (CBR) test, unconfined compressive strength (UCS) test, scanning electron microscope (SEM) test, X-ray energy dispersive spectroscopy (EDS) test and X-ray diffraction (XRD) test were carried out. Taking into account the two ages of 7 d and 28 d as well as the four types of nano-MgO content, the cement content was fixed at 4% in the test of employing nano-MgO modified cement-reinforced waste road recycled aggregates (MCRA). The outcomes of the mechanical tests indicate that adding nano-MgO has the potential to improve mechanical qualities; All MCRA specimens with nano-MgO exhibit CBR values that satisfy the criteria for extremely heavy and extremely heavy traffic intensities.

## I. INTRODUCTION

Every country in the globe has an increasingly well-developed road network, and the amount of building materials consumed is rising at an exponential rate. A significant quantity of solid trash related to building is also produced as a result of the industry's success and the road system's advancement [1,2]. Recycled aggregate is created by sorting, crushing, and cleaning these urban solid waste products. This aggregate is then used in place of natural aggregate in the road base. In addition to helping to store natural resources, this resource reuse approach successfully improves the ecological environment and creates a situation where both the environment and the economy win. It is currently one of the worldwide issues that needs to be researched and resolved [3,4]. repurposed aggregate [8] Have conducted performance research on the subbase or base course using recycled aggregate rather than granular material, and have also shown that bearing capacity is significantly impacted by the degree of compaction. Roads were the subject of Xiao et al.'s [9] examination of the mechanical characteristics of unconfined compressive strength and splitting strength under freeze-thaw cycles using cement-cured recycled aggregates with a 4% cement content. Wu et al. [10] used the unconfined compressive strength test, splitting tensile test, and compressive resilience modulus test to investigate the performance of cement stabilized pavement foundation with varying recycled aggregate amounts. The test results reveal that when the content of recycled aggregate is 60 %, the best.

An abundant element in the crust of the Earth is magnesium. There are many different sources of raw materials for the production of nano-MgO material, one of which is the efficient recovery of MgO from magnesite tailings [20]. Because of its exceptional qualities of high surface activity and high surface energy, nano-MgO is frequently utilized to change cement-based materials [21–23]. In order to investigate the modification effect of nano-MgO on the mechanical characteristics of clay, Gaoet al. [24] conducted unconfined compressive strength tests and analyzed the nano-effect of nano-MgO. The experimental findings shown that when the amount of nano-MgO in the clay grows, so does its compressive strength. Additionally, nano-MgO can enhance the cementation and void filling of the clay particles, which contributes to the solidification effect testing with a microscope. Studies have demonstrated that nano-MgO may considerably improve the stiffness of clay and generate a physical connection between the clay particles, which can shift clay particles from layered sheet structures to concentrated structures. The impact of nano-MgO on cement-stabilized dredged sediment's mechanical properties was investigated by Lang et al. [27]. The results of the optical microscope and unconfined compressive strength tests demonstrated that nano-MgO can greatly increase the dredged sediment's compressive strength. Additionally, nano-MgO gives the dredged sediment a physical filling and bonding effect, which effectively improves the structural integrity. In conclusion, a multitude of studies demonstrate that adding nano-MgO can effectively enhance the mechanical characteristics of soils stabilized with cement. Although very uncommon, research on nano-MgO reinforced cement-stabilized recycled aggregate is extremely important.

## II. EXPERIMENTAL MATERIALS, SCHEMES, AND METHODS

### 2.1. Materials

**Materials used for CBR AND UCS**

This test's recycled aggregate comes from North Erhuan Road's building site in Shaoxing, Zhejiang Province. These are repurposed fine and coarse aggregates, obtained by crushing and screening the waste road subgrade's bottom aggregate, with a particle size of less than 31.5 mm. As seen in Fig. 1, the first three steps of the RA preparation process align with the findings of the research conducted by Lv et al. [28]. The original road subgrade is shown in Fig. 1a. It is the broken RA in Fig. 1b. And the RA that was brought to the lab is shown in Fig. 1c. The distinction is that, as per the intended gradation in Fig. 1d, RA must be sieved using conventional sieves. In line with the Materials Test Procedures

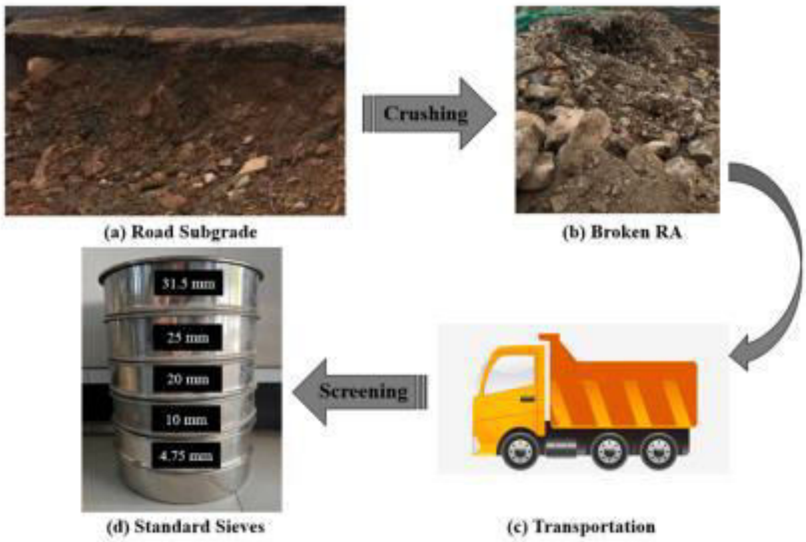



**Fig. 1. RA preparation process**

Stabilized with Inorganic Binders for Highway Engineering (JTG E51- 2009) [29], recycled aggregate is subjected to an indoor geotechnical test, and Table 1 displays the inorganic binder performance indices. The aggregate with a particle size higher than 4.75 mm in the inorganic binder was chosen as the coarse aggregate, and the aggregate with a particle size smaller than 4.75 mm was employed as the fine aggregate, per the Test Methods of Aggregate for Highway Engineering (T0305-1994) [30]. Tables 2 and 3 exhibit the fundamental physical property indices for coarse and fine aggregates, respectively. Referring to the standards of Technical Guidelines for Construction of Highway Roadbases (JIG/T F20-2015) [31], this test shall be blended.

**Equipment**

Shanghai Shengke Instrument Equipment Co., Ltd.'s MQS-2 pavement material strength tester is used by the CBR test apparatus. The force measuring ring has a 100kN capacity, and the penetration speed is 1 mm/min. Shenzhen Sansi Zongheng Technology Co., Ltd. manufactures the JKYB05C universal material testing machine, which is used in the UCS test. The X-ray diffractometer used in the XRD test is the PIXcel3D, made by PANalytical B.V. (Netherlands). The tungsten filament high and low vacuum scanning electron microscope JSM-6360LV, made by JEOL Ltd. (Tokyo, Japan), is used in the SEM test. The X-act spectrometer, made in Oxford, UK, is used in the EDS test.

**Schemes**

Table 7 displays the experimental schemes used in this paper for the CBR and UCS tests. Table 7 shows the mass ratio of cement to recycled aggregate, the mass ratio of nano-MgO to recycled aggregate, and the mass ratio of water to mixture for the three different contents.

**CBR specimen preparation**

The following phases comprise the manufacturing process of CBR test specimens: (1) To guarantee the consistency of particle size composition, the recycled aggregate was first placed in the oven to dry. After that, it was filtered through standard sieves with varying apertures in accordance with the recycled aggregate gradation (see Table 4). (2) The test materials were mixed equally after being weighed in accordance with the mix proportion. (3) Three layers of the combined materials were put into the CBR mold, and each layer was roughened and scraped after being hammered 98 times with a 98% compaction. (4) The specimens underwent the usual curing process, and Fig. 2a displays the CBR specimen.

**UCS specimen preparation**

The Test Procedures of Materials Stabilized with Inorganic Binders for Highway Engineering (JTG E51-2009) [29] were followed in the preparation of the UCS specimens. The following are the precise steps: (1) To guarantee a constant particle size composition, the recycled aggregate was first dried in an oven before being filtered through conventional sieves with varying apertures in accordance with the recycled aggregate gradation (see Table 4). (2) The test materials were mixed equally after being weighed in accordance with the mix proportion. (3) After the blended materials were added to the UCS mold, they were compressed using a pressure testing apparatus and then put into a demoulding machine. (4) After the specimens underwent the usual curing process, the UCS specimen is visible as indicated.

(a) CBR (b) UCS

**Fig. 2.** Specimen diagram.

**Table 1 Inorganic mixture performance**

| Indicator name | Non uniformity coefficient | Old mortar content (%) | Crush value (%) | Needle flake content (%) | Debris content (%) |
|---|---|---|---|---|---|
| Index value | 11.14 | 4.62 | 10.50 | 7.45 | 0.06 |
| Requirements | ≥ 5 | ≤ 18 | ≤ 30 | ≤ 18 | ≤ 0.5 |

**Table 2 Basic physical properties of recycled coarse aggregate**

| Indicator name | Crush value (%) | Mud content (%) | Apparent density (kg/m3 |
|---|---|---|---|
| Index value | 12.3 | 20.5 | 2.53 |

**Table 3 Basic physical properties of recycled fine aggregate**

| Indicator name | Moisture content (%) | PlasticityIndex | Proportion | Mud content(%) | Apparentdensity (kg/m3 ) |
|---|---|---|---|---|---|
| Index value | 12.9 | 16.6 | 2.68 | 20.5 | 2.67 |

**Table 4 Recycled aggregate grading.**

| Particle size D (mm) | 0 ≤ D ≤ 4.75 | 4.75 < D ≤ 10 | 10 < D ≤ 20 | 20 < D ≤ 25 | 25 < D ≤ 31.5 |
|---|---|---|---|---|---|
| Quality score (%) | 35 | 22 | 25 | 9 | 9 |

**Table 5 Ordinary Portland cement composition.**

| Element | SiO2 | Al2O3 | Fe2O3 | MgO | SO3 | K2O | Na2O | Mn2O3 | CaO |
|---|---|---|---|---|---|---|---|---|---|
| Content (%) | 19.87 | 4.90 | 3.40 | 1.25 | 2.01 | 0.45 | 0.69 | 0.35 | 65.10 |

**Table 6 Nano-MgO physical parameters.**

| Product | Average particle size (nm) | Product purity (%) | Theoretical density (g/cm3 ) | Meltingpoint (°C) | Boilingpoint (°C) | Crystalform | Dispersion |
|---|---|---|---|---|---|---|---|
| Nano-MgO | 15–20 | 99.9 | 3.580 | 2850 | 3600 | Near spherical | Gas phase preparation |

**Table 7 CBR and UCS test schemes.**

| Specimen number | Cement content (%) | Nano-MgO content (%) | Moisture content (%) | Dry density (g/cm3 ) | Age (d) |
|---|---|---|---|---|---|
| 0%MCRA | 4 | 0 | 8 | 2.15 | 7,28 |
| 0.2%MCRA | | 0.2 | | | |
| 0.3%MCRA | | 0.3 | | | |
| 0.4%MCRA | | 0.4 | | | |
| 0.5%MCRA | | 0.5 | | | |

## III. RESULTS AND DISCUSSION

Figure 3 displays the p-l curves of MCRA specimens at 7 and 28 days old, as determined by the CBR test. Table 8 provides a summary of the CBR values. According to Fig. 3 and Table 8, the CBR values of 0.2%, 0.3%, 0.4%, and 0.5% MCRA grew by 38.5%, 63.3%, 80.5%, and 66.3%, respectively, at the age of 7 days when compared to 0% MCRA. When compared to 0%MCRA, it grew by 17.9%, 40.0%, 63.3%, and 36.3% at the age of 28 days. It is discovered that the MCRA specimens' strength has increased more noticeably at 7 days of age. At 28 days old, the CBR readings were 0.2 and 0% MCRA.

**3.1.1. CBR value benchmarking specification requirements**

The CBR strength standard requirements for graded crushed stone materials used as road basis and subbase are displayed in Table 9. The measured CBR values of various externally mixed materials serve as a guidance for the project's actual implementation. The corresponding roadway grade criteria are represented by each letter in Table 9. Equation (1) proposes the surplus reserve K as a technique to explain the excess of various admixtures to CBR strength norms of different roadway grades. The larger the excess reserve and K value of various admixtures in relation to the highway grade specifications, the higher the engineering safety; conversely, the lower the safety.

Where CBRs is the equivalent standard value for various grades and CBR is the measured CBR value of various materials. Table 10 displays the road grade requirements at 7 and 28 days old, respectively, as satisfied by the measured CBR value and the surplus reserves. Table 10 shows that at 7 d, 0% MCRA satisfies the standards of the second-class and below highways' heavy traffic grade. It can meet the expressway and the very heavy and extra heavy traffic of the first-class highway after adding nano-MgO. When the MCRA specimens were 28 days old, they all complied with the first-class expressways' extremely heavy and super heavy traffic grade standards.

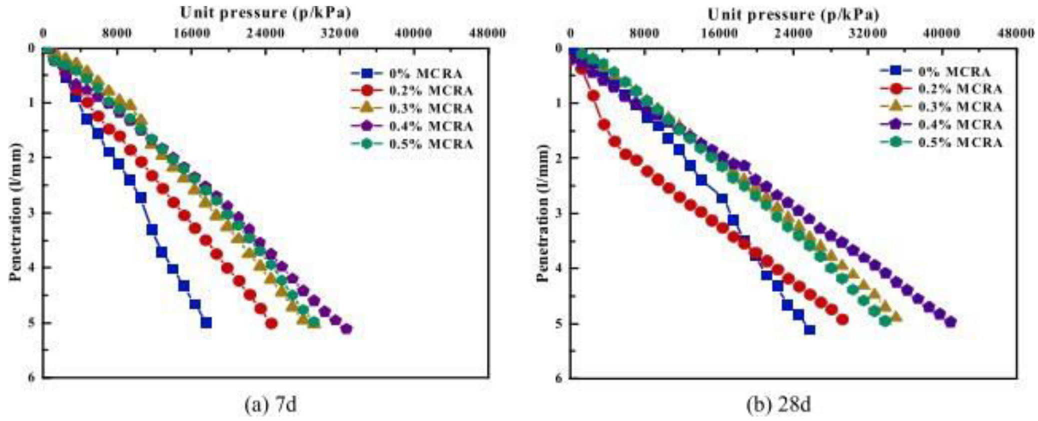



Fig 3. The p-1 curve of MCRA specimens under different nano-MgO content

**Table 8 Summary of CBR values (%) of MCRA specimens**

| Specimen number | 7d | 28d |
|---|---|---|
| 0%MCRA | 169 | 240 |
| 0.2%MCRA | 234 | 283 |
| 0.3%MCRA | 274 | 336 |
| 0.4%MCRA | 305 | 392 |
| 0.5%MCRA | 281 | 327 |

**Table 9 CBR strength materials of graded crushed stone materials**

| Structural layer | Highway | Extremely heavy and extra heavytraffic | Heavy traffic | Medium and light traffic |
|---|---|---|---|---|
| Subgrade | Expressway and first-class highway | >=200(T1) | >=180(H1) | >=160(M1) |
| | Second-class and lower highways | >=160(T2) | >=140(H2) | >=120(M2) |
| subbase | Expressway and first-class highway | >=120(T3) | >=100(H3) | >=80(M3) |
| | Second-class and lower highways | >=100(T4) | >=80(H4) | >=60(M4) |

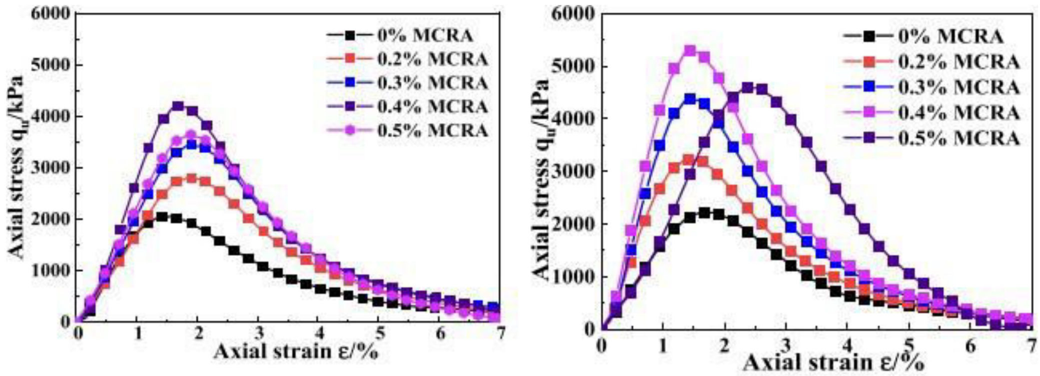
**Table 10 CBR values of different materials meet the requirements of highway grades**

| Specimen number | Age | CBR value | Highway grade | Surplus reservek (%) |
|---|---|---|---|---|
| 0%MCRA | 7d | 169 | H2 | 21 |
| 0.2%MCRA | | 234 | T1 | 17 |
| 0.3%MCRA | | 274 | T1 | 37 |
| 0.4%MCRA | | 305 | T1 | 53 |
| 0.5%MCRA | | 281 | T1 | 41 |

| | | | | |
|---|---|---|---|---|
| 0%MCRA | 28d | 240 | T1 | 20 |
| 0.2%MCRA | | 283 | T1 | 42 |
| 0.3%MCRA | | 336 | T1 | 68 |
| 0.4%MCRA | | 392 | T1 | 91 |
| 0.5%MCRA | | 327 | T1 | 64 |

**UCS test -Stress-strain curve**

For every group of mix proportions, a total of 5 specimens were set in order to lower the test error. The five stress-strain curves obtained from each group of UCS tests were normalized to obtain the stress-strain curves of MCRA specimens with varying nano-MgO concentrations in Fig. 4. The stress-strain curves of the MCRA specimens are all softening curves, as seen in Fig. 4.




(a) 7d (b) 28d

Fig 4. The stress-strain curves of MCRA specimens.

**Peak intensity**

The peak intensities of the MCRA specimens obtained from the stress-strain curves in Fig. 4 at 7 d and 28 d ages are displayed in Fig. 5. It can be shown from Fig. 5 that the peak intensities of 0.2 %MCRA, 0.3 %MCRA, 0.4 %MCRA and 0.5 %MCRA at 7 d age were 2810 kPa, 3444 kPa, 4197 kPa and 3640 kPa, respectively. which, in turn, are 36.3%, 67.1%, 103.6%, and 76.6% greater than the 0% MCRA. At the age of 28 days, the peak intensities of 0.2%, 0.3%, 0.4%, and 0.5% MCRA were, respectively, 3240 kPa, 4381 kPa, 5305 kPa, and 4607 kPa. These values were 46.4%, 96.5%, 138.0 %, and 106.7% greater than the corresponding value of 0% MCRA. Everybody

The peak intensity of MCRA specimens revealed a tendency of first significantly increasing and then dropping at the same age as the increase in MgO content. The ideal nano-MgO content is 0.4% since the unconfined compressive strength of 0.4 %MCRA reaches its highest value. The main reason why excessive nano-MgO causes MCRA specimens to lose strength is that it prevents the particles from being freely dispersed, which limits the cement hydration reaction. Agglomeration and accumulation also occur, which results in a lack of a cemented connection structure between the particles, which further reduces strength.

**Residual strength**

As per the Standard for Geotechnical Testing Method (GBT50123-2019) [32], the unconfined compressive strength test's maximum strain is commonly determined by taking the peak strain plus 3–5%. The peak strain of this test is about 1.5–2 %, thus the stress at 6 % of the strain is taken as the equivalent residual strength, and the residual strength of MCRA specimens at 7 d and 28 d ages is plotted in Fig. 6. Figure 6 illustrates how the age of MCRA specimens causes a decrease in residual strength. The residual strength of MCRA specimens grows dramatically at the same age and subsequently drops as the nano-MgO content increases, reaching its maximum when the residual strength of 0.3% MCRA.

**Brittleness index**

Brittleness is a crucial characteristic of geotechnical materials that can be used to describe a material's manner of failure. In order to analyze the degree of brittleness in materials, the brittleness index was created [33–35]. The hardness of the sample decreases as the brittleness index approaches 1, and vice versa. Equation (2) [36] displays the brittleness index calculation formula:

I = qmax – qres/qmax

where qmax is the peak intensity (kPa), qres is the residual strength (kPa), and I is the brittleness index. Table 10 displays the MCRA specimens' brittleness index, which was determined using Equation (3). The brittleness index of the MCRA specimens is found to increase significantly with an increase in nano-MgO content; the more content, the faster the index increases, suggesting that the more obvious the brittle failure of the specimen is, the more nano-MgO content there is. Simultaneously, MCRA specimens' brittleness index at age 28 days is higher than it is at age 7 days. The primary cause is that the specimens doped with nano-MgO exhibit increased brittleness due to

**Unconfined compressive strength benchmarking specificationrequirements**

As to the Technical Guidelines for Construction of Highway Roadbases (JIG/T F20-2015) [31], the criteria of different road grades can be fulfilled by the unconfined compressive strength of different materials. If this study satisfies the project's practical application criteria at the age of 7d, it will be determined by using the unconfined compressive strength standard Table 11 of the cement stabilized material; the corresponding highway grade requirements are represented by the letters below. Table 12 displays the road grade standards that the measured unconfined compressive strength of MCRA specimens meets. It is discovered that 0.2% and 0% MCRA

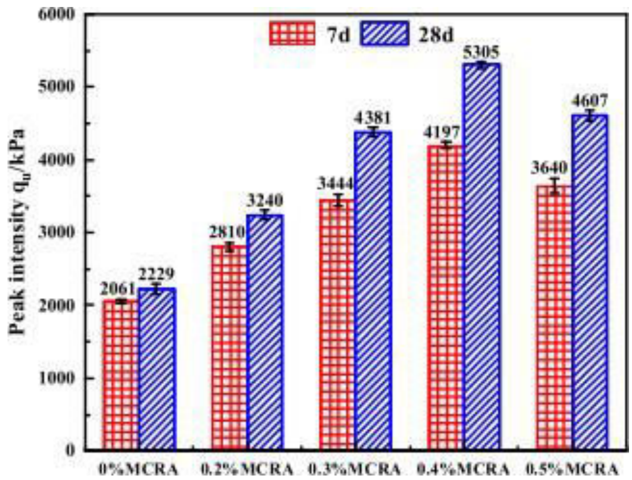



Fig 5. The peak intensity of MCRA specimens

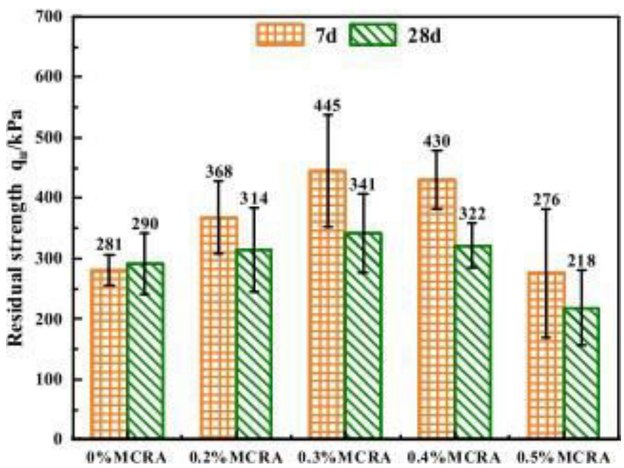



Fig. 6. The residual strength of MCRA specimens.

**Table 11 :Summary of brittleness Index**

| Specimen number | **7d** | **28d** |
|---|---|---|
| 0%MCRA | 0.864 | 0.870 |
| 0.2%MCRA | 0.869 | 0.903 |
| 0.3%MCRA | 0.871 | 0.922 |
| 0.4%MCRA | 0.898 | 0.939 |
| 0.5%MCRA | 0.924 | 0.953 |

**Table 12: Cement stabilized material 7d unconfined compressive strength standard (MPa).**

| Structural layer | Highway | Extremely heavy and extra heavytraffic | Heavy traffic | Medium and light traffic |
|---|---|---|---|---|
| Subgrade | Expressway and first-class highway<br><br>Second-class and lower highways | 5.0–7.0(T1)<br><br>4.0–6.0(T2) | 4.0–6.0(H1)<br><br>3.0–5.0(H2) | 3.0–5.0(M1)<br><br>2.0–4.0(M2) |
| subbase | Expressway and first-class highway<br><br>Second-class and lower highways | 3.0–5.0(T3)<br><br>2.5–4.5(T4) | 2.5–4.5(H3)<br><br>2.0–4.0(H4) | 2.0–4.0(M3)<br><br>1.0–3.0(M4) |

**Table 13: The unconfined compressive strength of different materials meets the requirements ofthe road base level**.

| Specimen number | 7d unconfined compressivestrength (MPa) | Highway grade |
|---|---|---|
| 0%MCRA | 2.06 | M2 |
| 0.2%MCRA | 2.81 | M2 |
| 0.3%MCRA | 3.44 | M1 |
| 0.4%MCRA | 4.20 | H1 |
| 0.5%MCRA | 3.68 | M1 |

MCRA can handle the medium and light traffic on second-class and lower highways; expressways, medium and light traffic on first-class highways, and expressways; heavy traffic on expressways and first-class highways can be handled by MCRA; 0.4 %MCRA performs best.

## IV. CONCLUSION

Nano-MgO incorporation into CRA has a certain enhancement impact. As the nano-MgO content rose, the MCRA specimens' CBR value and unconfined compressive strength first increased and subsequently declined. Both the unconfined compressive strength of 0.4%MCRA and the CBR value attained their maximum values. The brittleness index of MCRA specimens increased dramatically as the nano-MgO content increased. The more the content, the faster the brittleness index grew and the more evident the brittle failure.

The CBR values of the MCRA specimens added with nano-MgO at the ages of 7 and 28 days all meet the specifications of the expressways and the very heavy and extra heavy traffic grades of the first-class highways; at the age of 28, the 0.4% MCRA project has the highest safety degree. First-class highways and expressways can both be built to the heavy traffic grade criteria and unconfined compressive strength of 0.4% MCRA. The ideal dosage of nano-MgO is 0.4%. The CB under the curing ages of 7 and 28 days with a MgO concentration of 0.4%, allowing them to meet the highest road grade of all the specimens. In the meanwhile, the 0.4%MCRA specimen's mild degree of brittleness means that engineering won't be significantly harmed.

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