Effect of rapid set binder on early strength and permeability of HES latex modified road repair pre-packed concrete

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Abstract. The early strength development characteristics and permeability resistance of high early strength (HES) pre-packed road repair concrete incorporating a rapid-set binder material were evaluated for emergency repairs to road pavement. The rapid-set binder is a mixture of rapid-set cement and silica sands whose fluidity improves with the addition of styrene butadiene latex (latex). The resulting mixture has a compressive strength of 21 MPa or higher and a flexural strength of greater than 3.5 MPa after 4 hours, the maximum curing age allowed for emergency repair materials. This study examines the strength development properties and permeability resistance of HES latex-modified pre-packed road repair concrete using a rapid-set binder as a function of the latex-to-binder mixing ratio at values of 0.40, 0.33, 0.29 and 0.25. Both early strength development properties and permeability resistance increased as the ratio of latex to rapid-set binder decreased. The mixture showed a compressive strength of 21 MPa or higher after 4 hours, which is the design standard of emergency repair concrete, only when this ratio was 0.29 or lower. A flexural strength of 3.5 MPa or greater was observed after 4 hours only when this ratio was 0.33 or lower. The standard for permeability resistance, less than 2,000 C of chloride after 7 days of curing, was satisfied by all ratios. The ratio of latex to rapid-set binder satisfying all of the conditions for an emergency road repair material was 0.29 or less.

1. Introduction
Reparations to old paved roads are in continuous demand. As traffic considerations require that roads be reopened as soon as possible following a repair, many diverse studies have led to design standards for materials used in emergency road repairs [1-7]. Various methods have been explored to ensure minimal closure; for example, a precast concrete pavement as a replacement for the damaged concrete pavement can be used [8-12]. With precast concrete pavement structures, immediate re-opening to traffic is possible once the precast sections are in place [8-12]. However, with precast concrete pavement structures, rough handling during transportation and installation can lead to cracking, which can increase the water permeability [11, 12]. Another method is to use ASTM Type I cement with a
hardening accelerator [13, 14]. Pavement repair materials specify a minimum curing time of 72 hours (3 days) as the standard curing period for ASTM Type I cement before re-opening to traffic and requires the compressive strength to exceed 22 MPa and the flexural strength to exceed 4.5 MPa [8, 11, 12]. However, ASTM Type I cement alone does not meet these requirements; a hardening accelerator is needed [11, 12]. The third approach is to use rapid-set cement concrete [11, 12, 15, 16]. Rapid-set cement concrete is the primary material used in such repairs, but rapid-set cement generates a high heat hydration to attain its early strength, which heats the surrounding road structure and increases the migration of vapours [5, 6]. Under actual field conditions, this migration is often restricted to the repair structure itself, resulting in tensile stress and the formation of micro cracks [5, 6]. These cracks increase the water permeability of the repair structure, which leads to a diverse range of destruction mechanisms [5, 6]. Thus, the repair loses function and raises the necessity of another repair within a short time. To solve this problem, this study evaluates the performance of a HES road repair material consisting of pre-packed concrete incorporating styrene butadiene latex (latex) and rapid-set binder materials. In a typical road repair using this material, the old road pavement to be repaired is removed and the void is filled with coarse aggregates. The rapid-set binder material is then mixed with latex, the mixture is poured into the aggregate-filled void and the repair is infused via vibration compaction. At this point, the mixture of latex and rapid-set binder should have sufficient fluidity to be self-levelling. After infusion, the surface is finished to end the road repair. Mixing latex into the rapid-set binder secures the early strength and sufficient workability while maintaining or improving durability [17-20]. The addition of latex increases the workability of unhardened concrete and reduces the ratio of water to cement [17-20]. It can also prevent the separation of materials due to the viscosity of latex itself and can increase the flexural strength, tensile strength and deformation capacity after the concrete hardens, thereby improving adhesion, water-tightness, resistance to freezing/melting, anti-abrasion properties and chemical resistance [17-20]. In this study, the early strength development properties and permeability resistance of HES latex-modified pre-packed concrete for emergency road repair were evaluated.

2. Materials and methods

2.1. Materials
The rapid-set binder material used in this study was a mixture of rapid-set cement and silica sands manufactured by Jung-Ang Polytec in Korea. The mixing ratio of rapid-set cement to silica sands was 1:1. The chemical compositions of the rapid-set cement are shown in table 1. Coarse aggregates were crushed stone with a maximum dimension of 25 mm and a density of 2.62 g/mm³. The physical properties of the latex, made by Korean Jung-Ang Polytec, are listed in table 2.

| SiO₂ (%) | Al₂O₃ (%) | Fe₂O₃ (%) | CaO (%) | MgO (%) | K₂O (%) | SO₃ (%) |
|----------|-----------|-----------|---------|---------|---------|---------|
| 13±3     | 17.5±3    | 3>        | 50±3    | 2.5>    | 0.21    | 14±3    |

| Solids (%) | Content | Styrene Content (%) | Butadiene Content (%) | Surface Tension (dyne/cm) | Particle Size (Å) | Viscosity (cps) |
|------------|---------|---------------------|-----------------------|---------------------------|-------------------|-----------------|
| 8          | 34±1.5  | 66±1.5              | 30.57                 | 1700                      | 42                |

2.2. Mix proportions and manufacturing of test specimens
For road pavement repairs made with rapid-set cement, AASHTO and the road traffic offices of each American state, as well as the Korean Highway Corporation, have defined 4 hours as the minimum curing period prior to reopening traffic over the repair [8, 21]. The standards for traffic reopening are a compressive strength of 21 MPa or higher and a flexural strength of 3.5 MPa or more [8, 21]. This
study focuses on road repairs using rapid-set cement, the goals were to obtain a material that meets these standards. Permeability has the greatest effect on the life span and durability of road pavement. The Korean Highway Corporation has suggested a limit of 2000 C or lower after 7 days of curing, based on tests of chloride ion permeation in accordance with ASTM C1202 [21]. The mixing ratios of latex to binder used in this study are presented in table 3.

Table 3. Mix Proportions of HES latex modified road repair pre-packed concrete.

| Type of mix | Rapid set binder materials (kg/m³) | Latex (kg/m³) | Corse aggregate (kg/m³) |
|-------------|-----------------------------------|---------------|------------------------|
| 0.40        | 575                               | 218           | 1450                   |
| 0.33        | 627                               | 210           | 1450                   |
| 0.29        | 690                               | 198           | 1450                   |
| 0.25        | 732                               | 184           | 1450                   |

Specimens for compressive strength tests was made by packing coarse aggregates into a cylindrical frame with a diameter of 100 mm and a height of 200 mm. Rapid-set cement and silica sands were mixed together. The latex was then poured into this rapid-set binder material and mixed for 1 minute and 30 seconds. After mixing, the cylindrical form packed with coarse aggregates was put on the vibration table, and the rapid-set binder materials were poured into it while the table was vibrating. Flexural strength specimens were produced in the same way except in a 100 × 100 × 400-mm rectangular frame.

2.3. Test methods

2.3.1. Strength tests. Compressive strength tests were performed in accordance with ASTM C 39, flexural tests were conducted in accordance with ASTM C 78/C78M were conducted in accordance with ASTM C 496/C496M-11. Tests were performed after 4 hours of curing.

2.3.2. Chloride ion penetration tests. Chloride ion penetration tests were conducted in accordance with ASTM C 1202-94. Specimens measuring 150 × 50 mm were tested after 4 hours and 7 days of curing. The test apparatus for chloride ion penetration tests is shown in figure 1.

Figure 1. Chloride ion penetration test set-up.
3. Test results and discussion

3.1. Compressive strength

The compressive strength characteristics of HES latex-modified pre-packed road repair concrete for emergency road repair are shown in figure 2. As the mixing ratio of latex to rapid set binder material got smaller, the compressive strength tended to increase. When this ratio was below 0.29, the resulting material satisfied the compressive strength requirement for an emergency road repair material (21 MPa) after 4 hours, which suggests that the addition of latex retarded the manifestation of early strength. Furthermore, the lower proportion of rapid-set binder material likely did not allow sufficient early strength to develop. To satisfy both of these goals, the proportion of rapid-set binder must be higher. Thus, a latex-to-binder ratio of 0.29 or lower was deemed sufficient to satisfy the standards of an emergency road repair material.

![Compressive strength of HES latex modified road repair pre-packed concrete.](image)

Figure 2. Compressive strength of HES latex modified road repair pre-packed concrete.

3.2. Flexural strength

The flexural strength test results are given in figure 3. The standard for flexural strength is 3.5 MPa after 4 hours. These standards were met at a latex-to-binder ratio of 0.33 or lower. These data show that the addition of latex to concrete has a greater influence on tensile and flexural strength than on compressive strength. As latex increases the binding forces between materials when the concrete receives flexural or tensile stresses, unlike compressive strength, the flexural strength requirements were satisfied even at a latex-to-binder ratio of 0.33. Flexural strength tended to increase as this binder ratio decreased.

![Flexural strength of HES latex modified road repair pre-packed concrete.](image)

Figure 3. Flexural strength of HES latex modified road repair pre-packed concrete.
3.3. Chloride ion penetration

The chloride ion permeability resistance of the evaluated road repair concrete is shown in figure 4, and the permeability standard according to ASTM C 1202 is presented in table 4. Chloride ion permeability tended to decrease as the latex-to-binder ratio decreased. Relative to the standard set in ASTM C 1202, the chloride ion permeability after 4 hours for the 0.40 and 0.33 mixtures was ‘high’, showing up to 4000 C. Conversely, the chloride permeability for the 0.29 and 0.25 mixtures was deemed ‘moderate’, measuring between 2000 and 4000 C. After 7 days of curing, the permeability of the 0.40 mixture was ‘low’, measuring 1000–2000 C, while the permeability of the 0.33, 0.29 and 0.25 mixtures was ‘very low’, measuring 1000 C or less. Furthermore, after 7 days, the standard of 2000 C was met by all of the evaluated mixtures. Thus, in general, the addition of latex reduced the permeability of the concrete blend by filling gaps and forming a thick latex film within the concrete. Therefore, all of the specimens exhibited excellent permeability resistance.

![Figure 4](image)

**Figure 4.** Chloride ion penetration of HES latex modified road repair pre-packed concrete.

| Charge passed (Coulombs) | Chloride permeability |
|--------------------------|-----------------------|
| 4000>                    | High                  |
| 2000-4000                | Moderate              |
| 1000-2000                | Low                   |
| 100-1000                 | Very low              |
| <100                     | Negligible            |

### Table 4. Chloride permeability based on charge passed.

4. Conclusions

This study evaluated the early strength development and permeability resistance characteristics of HES latex-modified pre-packed road repair concrete as a function of the ratio of latex to rapid-set binder. The test results can be summarized as follows:

- The HES latex-modified pre-packed road repair concrete formulations evaluated herein met the design standards for an emergency repair concrete only when the ratio of latex to rapid-set binder was 0.29 or lower.
- In the flexural strength tests, the mixing ratio of latex to rapid-set binder needs to be 0.33 or less to satisfy the conditions of 3.5 MPa after 4 hours.
- All of the HES latex-modified road repair concrete formulations met the chloride ion permeability standard of 2000 C set by ASTM C 1202. Chloride permeability decreased as the ratio of latex to rapid-set binder decreased.

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