# Frost-Resistance Evaluation of Fly Ash Concrete with L-grade Recycled Coarse Aggregate

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## 1. Introduction

With the increase of building renewal and demolition in recent years, the amount of concrete waste is also increasing. In addition, the supply of natural aggregate is decreasing. Therefore, the recycled aggregate (RA), which can reuse concrete waste and reduce the discharge of industrial waste has become an important aggregate from the viewpoint of environmental aspects. However, the promotion of recycled aggregate has the problem. The use of RA is limited due to the low quality.

In 2018, the specification (JIS A5022) has been revised in which L-grade RA can be used mixing with natural coarse aggregate for the recycled aggregate concrete (RAC) as M-grade RA.

In this study, the frost-resistance of concrete specimens prepared with limited RA replacement levels (20% and 50% by volume) of crushed coarse aggregate were studied and discussed. In addition, fly ash was used for 20% replacement of ordinary Portland cement to study the effect on the frost-resistance, and also to reduce the possibility of alkali-silica reaction of RAC. Meanwhile, with the prevalence of steam curing regime in precast construction industry, the performance of steam cured RAC needs to be further investigated. Thus, different curing methods were employed to compare the frost-resistance of concrete between by steam and normal curing condition. The main goal of this study is to further promote recycled aggregates as an environmental material.

## 2. Experimental Details

### 2. 1 Material

The RA used were named RAG, which was obtained by crushing the concrete from the old Building G in Sapporo. All collected RA was further sieved to the particle size of 5-20mm to serve as the recycled coarse aggregate in concrete.

The properties of aggregates were shown in Table 1. The crushed coarse aggregate (NA) with the particle size of 5-20mm and the crushed fine aggregate was used.

Table 1. Properties of aggregates

| Types | Surface-dry density (g/cm$^3$) | Oven-dry density (g/cm$^3$) | Water absorption(%) |
|---|---|---|---|
| Sand | 2.68 | 2.66 | 0.83 |
| NA | 2.62 | 2.54 | 3.01 |
| RAG | 2.41 | 2.26 | 6.59 |

The water absorption rate of RAG satisfies the definition of L-grade recycled aggregate related to JIS A5023.

The fly ash used was JIS Type II in JIS A6201.

The air-entraining agent used was the MasterAir202 and the air-entraining water reducer used was the Master Glenium SP8SV.

### 2. 2 Concrete Mixes

As indicated in Table 2, a total of three sets of concrete were mixed in which the replacement rate of RAG was 0%, 20% and 50% by volume, respectively. The amount of chemical admixture was adjusted according to the target air content 5.5% (±1.5%) and slump 12cm (±2.5cm).

For each series of concrete, 100×100×400mm prisms and 200×100m diameter cylinder were cast. The prisms were used to test the resistance of concrete to freeze-thaw cycles. The cylinders were cut into 100×120×20mm blocks and polished for microscopical determination of the Air-Void System (ASTM C457 Linear Traverse Method).

### 2. 3 Specimens Curing

Each series of concrete were cured under two curing methods. For steam curing, the concrete specimens after casting (without demolding) underwent a steam curing regime shown in Figure 1. After curing, specimens were demolded, put in the water until 7-days ages. And then specimens were covered with wet cloth, sealed by plastic bags and put into the constant temperature room at 20°C until the test ages were

Table 2. Mix proportions

| Series | Volume replacement ratio (%) | Fly Ash replacement ratio(%) | S/a (%) | Unit content (kg/m$^3$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Water | Binder (B) | | Sand | Coarse Aggregate | | Admixture | |
| | | | | | Cement | Fly Ash | Crushed | Crushed | Recycled | AE water reducer | AE Agent |
| | RAG/ (NA+RAG) | F/(C+F) | - | W | C | F | S | NA | RAG | SP8SV | MA202 |
| NAF | 0 | 20 | 45.5 | 157 | 269 | 67 | 823 | 962 | 0 | 2.15 | 32.32 |
| RAGF20 | 20 | | | 157 | 269 | 67 | 823 | 769 | 177 | 2.36 | 35.35 |
| RAGF50 | 50 | | | 157 | 269 | 67 | 823 | 481 | 442 | 2.36 | 40.4 |

reached (14-day).

For normal curing, molds were covered with sheets and cured in air for 24h before demolding. The demolded specimens were cured in water until 21-day ages. Then the specimens were put out from the water and covered with wet cloth, sealed by plastic bags and put into the constant temperature room at 20°C. The same wet cloth curing method was used to ensure the same wet conditions as steam cured specimens. The curing continued until the test ages (28-day).

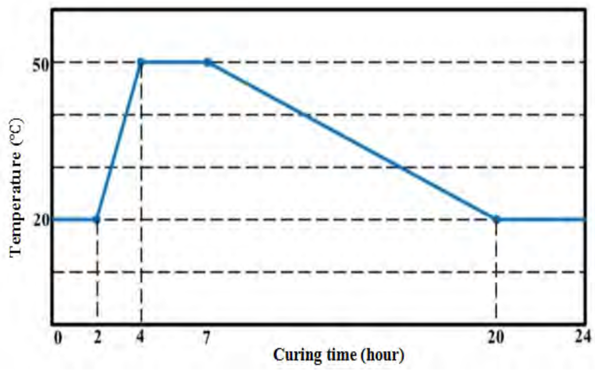


Figure 1. Steam curing regime

## 3. Results and Discussions

### 3. 1 Freeze-thaw test

In accordance with the JIS A1148, the freeze-thaw test was performed and the relative dynamic modulus of elasticity (RDME) was calculated at the basis of the fundamental resonant frequency.

The RDME was calculated as an index to evaluate the concrete performance based on the internal soundness of concrete specimens. The freeze-thaw test for a specimen should be stopped after 300 cycles of the specimen or when RDME of the specimen reached 60% of its initial value.

In this test, the average value of RDME of a set of three specimens was used to represent the RDME of each series of concrete. The RDME of all series of specimens in 300 cycles is over 60%. And final value of most of specimens except steam cured RAGF20 is over 80%, which can be considered to have a good frost-resistance.

Compared with normal cured specimens, RDME of steam cured RAGF20 and RAGF50 after the same freeze-thaw cycles showed lower results. However, RDME of steam cured NAF was higher than that of normal cured specimens. Steam curing method was expected to enhance the early-age durability of concrete, but in this test result was random. This was probably related to the early age of steamed cured specimens(14-day for steam cured concrete and 28-day for normal cured concrete) starting the freeze-thaw test. [1] The effect of steam curing need to be furture discussed under the same curing age .

### 3. 2 Air-Void System Analysis

In this analysis, the spacing factor and air content in the hardened concrete was measured. As shown in the Figure 2, one cross section of concrete was photographed in a two-dimensional image by high-performed camera. The air-void diameter from 30μm to 1000μm was counted. Then, the spacing factor and air content was calculated using the linear-traverse method.

The spacing factor of all the hardened concrete specimens were lower than 0.25mm. In this regard, it can be considered to have a good frost-resistance.

### 3. 3 Relationship between RDME and Spacing factor

The relationship of RDME result and Spacing factor results

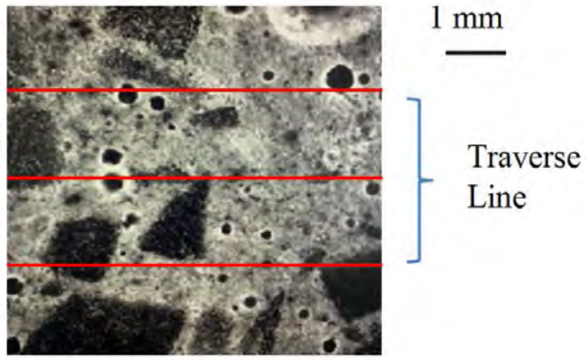


Figure 2. Air void system in harden concrete

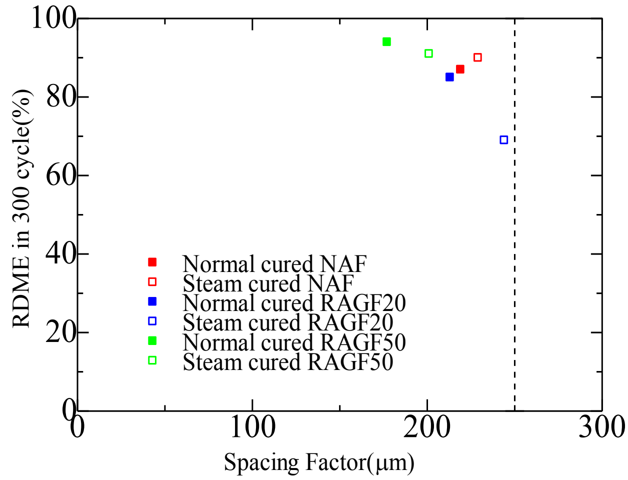


Figure 3. Relationship of RDME and spacing factor

of all specimens are shown in Figure 3. The spacing factor versus the RDME shows a trend that the lower the spacing factor, the higher the RDME.

The lower spacing factor means concrete has more closely spaced bubbles. Because a large number of closely spaced small air bubbles provide short flow distance to relieve excess pore pressure buildup and prevent damage. It will provide the better frost- resistance.

## 4. Conclusions

When the RA replacement level was relatively high, even for 50% by volume, two frost-resistance evaluation indexes of the RDME and spacing factor, showed good results in terms of the resistance to the frost damage.

For future study, the effect of steam curing on the frost resistance of recycled aggregate concrete with different repalcment levels needs to be further discussed.

## Acknowledgement

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## Reference

[1] Lianyao Xiong Investigation of Strength and Durability of Steam Curing Concrete with L-Grade Recycled Coarse Aggregate , Master Thesis, Hokkaido University, 2021