Uniaxial compressive strength of hydraulic, graded iron and steel slag base-course material produced at different manufacturers and its increase with curing time

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15th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering, Fukuoka, Japan November 10, 2015

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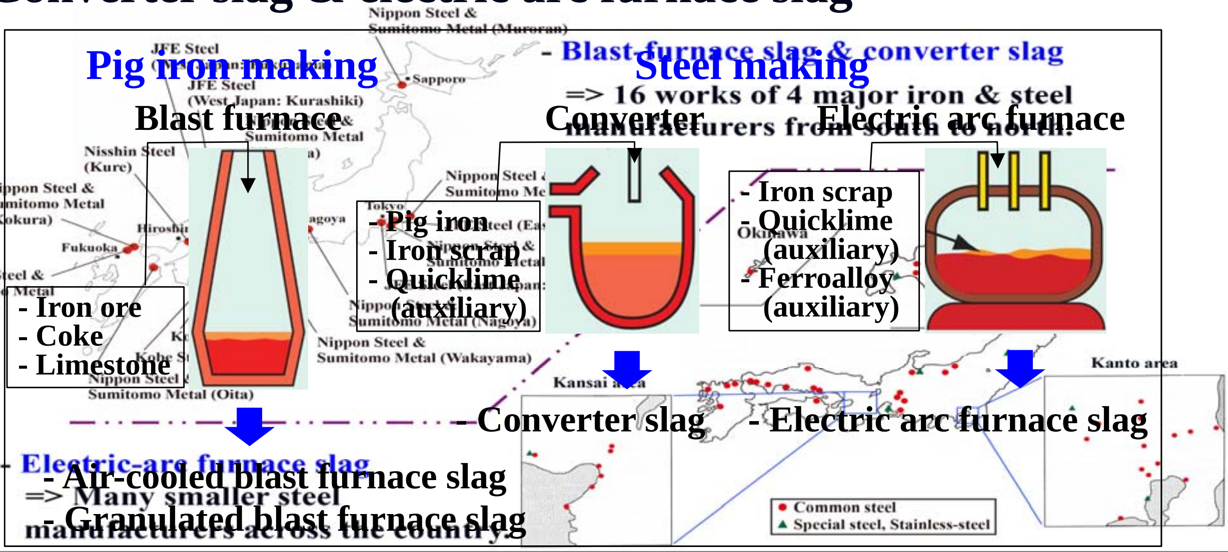
1. BACKGROUND AND INTRODUCTION

Iron and steel slag

- Produced during the process of making iron and steel, which is an industrial waste. at many locations
  - Blast-furnace slag & converter slag at 16 works of major iron and steel manufacturers
- Classified into 4 types:
  - Electric arc furnace slag at many relatively small steel manufacturers
  - Air-cooled blast-furnace slag & granulated blast-furnace slag
  - Converter slag & electric arc furnace slag



1. BACKGROUND AND INTRODUCTION

Iron and steel slag used in Japanese road construction by JIS (2013)

Item \ Type	Crusher-run iron and steel slag	Graded iron and steel slag	Hydraulic graded iron and steel slag	Crusher-run steel slag	Single-graded steel slag	Notes
Designations	CS-40, CS-30, CS-20	MS-25	HMS-25	CSS-30, CSS-20	SS-20, SS-5	The number indicates the max. grain size.
Usage	Subbase-course	Base-course	Base-course	Hot asphalt-stabilization	Hot asphalt mixtures	
Coloration	No	No coloration	No	-	-	Only for blast-
I	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
U	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Uniaxial compressive strength (MPa)	-	-	1.2 or larger (13-day cured)	-	-	
Density in saturated surface-dry	-	-	-	-	2.45 or	

A steady development of hydraulic nature in HMS !

- assumed in the Japanese design method of asphalt pavement

- Hydraulic graded iron and steel slag (HMS) consists of blast-furnace slag and steel slag with or without additives.
  - Some may not contain the granulated blast-furnace slag or any additives. *Their mixing ratios are often manufacturers' secrets.*

2. PURPOSE

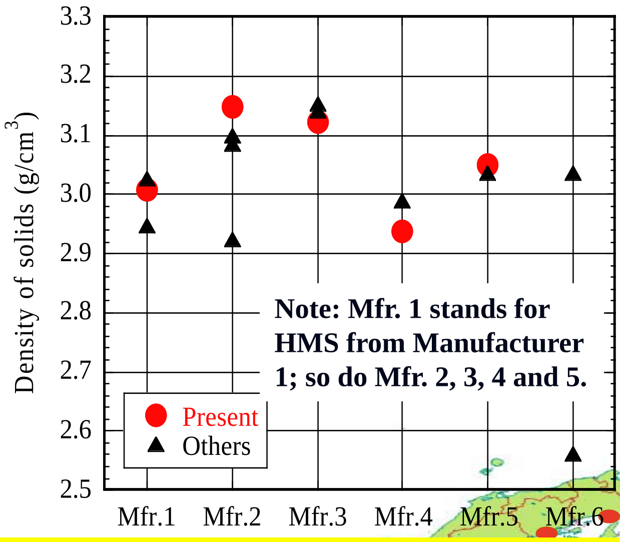
- **Does "HMS" base-course material from many different manufacturers exhibit similar mechanical characteristics, especially hydraulic nature?**

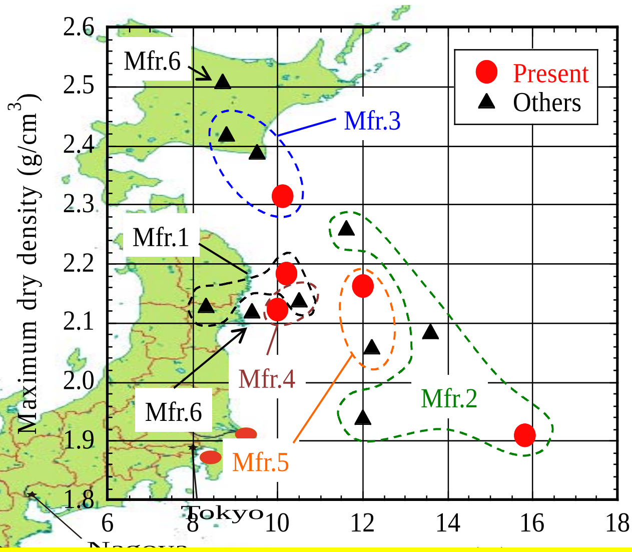
- **Had a great opportunity, in cooperation with Nippon Slag Association, of this experimental research program:**
  - **Mechanical characterization of HMS from 5 different manufacturers, especially uniaxial compressive strength and resilient modulus.**

- **To clarify whether or not the material exhibits a similar "hydraulic nature" regardless of its manufacturers for its rational use as base-course.**

3. TEST MATERIAL & SPECIMEN PREPARATION

- **HMS (hydraulic graded iron and steel slag) base-course material from well-known 5 manufacturers**





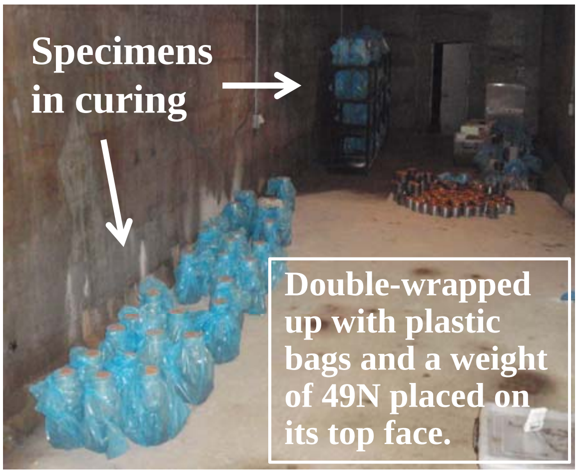
=> A difference in the constituents of each HMS & their mixing ratios.

- **ρ_s ranges from 2.9 to 3.2 g/cm^3: Mfr. 2 shows the largest ρ_s.**
- **Greater than common soil.**

- **$\rho_{d,max}$ and w_{opt} scatter in a wide range.**
- **Mfr. 3 exhibits largest $\rho_{d,max}$ with lower w_{opt}; Mfr. 2 shows smallest $\rho_{d,max}$ with highest w_{opt}**

3. TEST MATERIAL & SPECIMEN PREPARATION

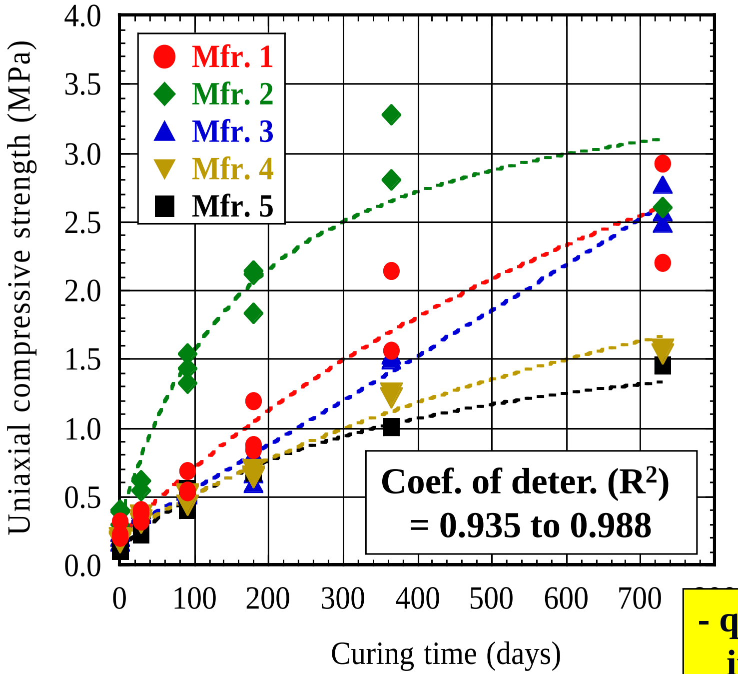
- Cylindrical Specimens
  - Size: 100 mm in diameter and 200 mm in height (excluding aggregates greater than 20 mm)
  - Degree of compaction: 95%
    - A prescribed amount of the material with its w_{opt} was taken and placed into a steel mould (inner diameter of 100 mm & height of 200 mm) in five stages
    - Compacted using a 4.5 kg rammer in such a way that the resulting ρ_d became 95% of the $\rho_{d,max}$.
- Curing of specimens: Stored them at an underground room with a temp. of about 20° C and a humid. of about 60% from 0 to 730 days.



- No. of specimens: 3 pieces/curing time/manufacturer

4. TEST RESULTS AND DISCUSSIONS

Uniaxial compressive strength (q_u) at each curing time



- q_u has a wide distribution at each curing time.
- q_u seems to increase with curing time, regardless of manufacturer.

e.g., Ratio of 730-day cured average q_u to 28-day cured one are:
7.0 for Mfr. 1,
5.1 for Mfr. 2,
6.8 for Mfr. 3,
4.6 for Mfr. 4,
5.6 for Mfr. 5.

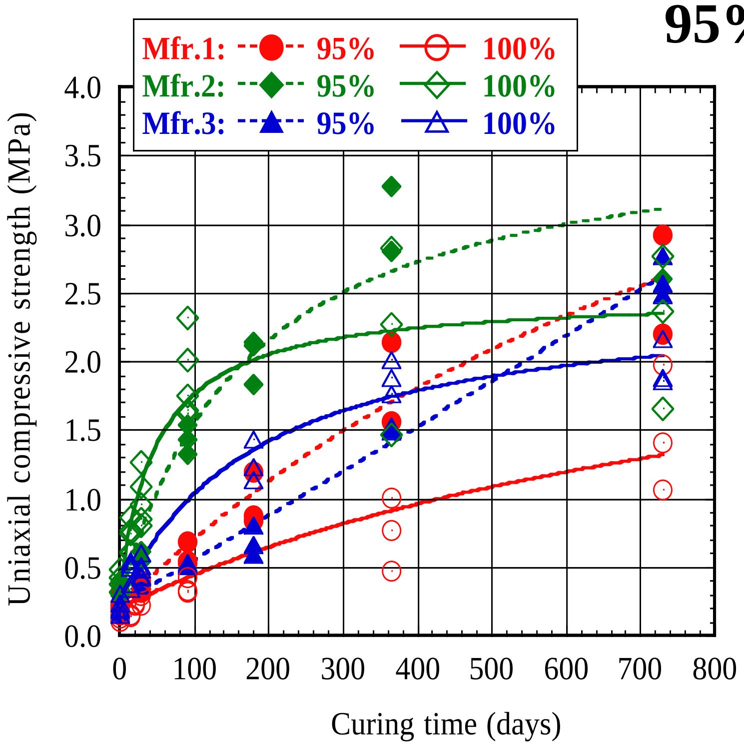
- q_u with a shorter curing time underestimates its long-term q_u regardless of manufacturer.

- Increasing tendency of q_u with time differs among manufacturers.
  e.g., Mfr. 3 seems to continue to increase further; Mfr. 5 is likely to settle down soon.

4. Test Results and Discussions

Uniaxial compressive strength (q_u)

95% vs. 100%-compacted



(With regression curves with the coefficient of determination, R^2 ranging from 0.830 to 0.988)

- **100%-compacted q_u also shows scattering at each curing time.**
- **95%-compacted q_u is not necessarily smaller than 100%-compacted one.**
  => The variable development of hydraulic nature overwhelms the expected influence of compaction efforts on the strength.

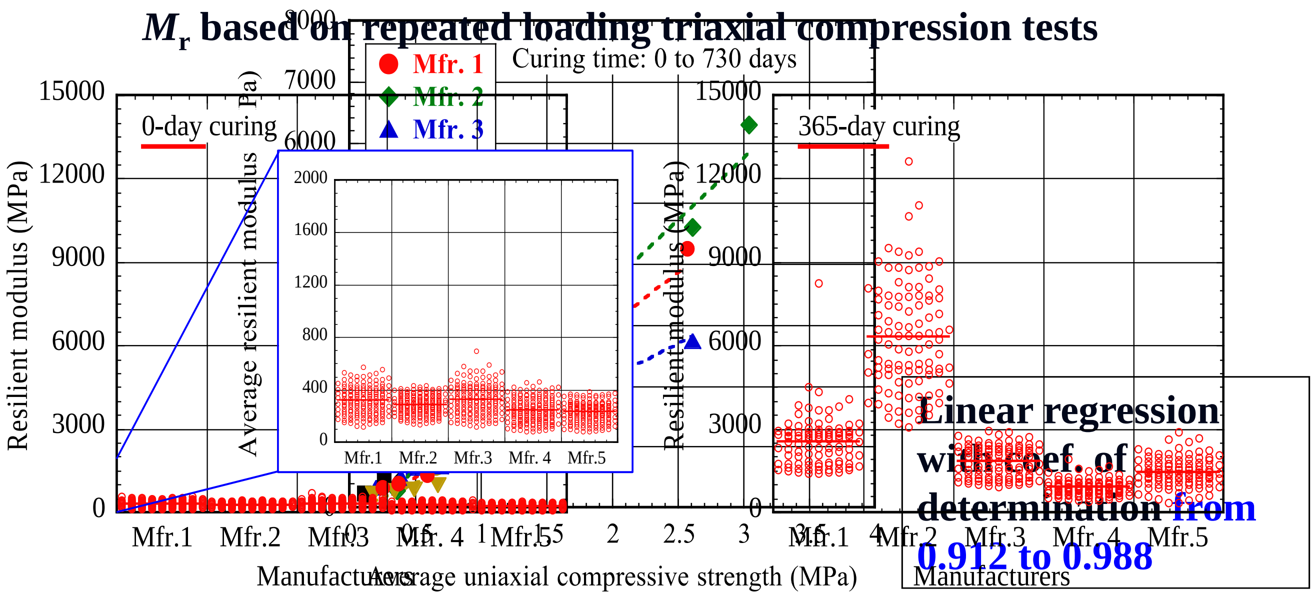
- **Increasing tendency of q_u with time differs even in the same manufacturer's HMS.**
  => Development of hydraulic nature may be different, depending on when it comes, even if the HMS comes from the same manufacturer.

4. Test Results and Discussions

Uniaxial compressive strength (q_u) vs. Resilient modulus (M_r)

In Average for each curing time for each manufacturer

M_r based on repeated loading triaxial compression tests



- **A strong correlation between average q_u and average M_r exists.**
  => Can estimate average M_r from average q_u for each manufacturer.
- **For a given average q_u, M_r differs among manufacturers.**

5. CONCLUSIONS

From this study, the followings can be pointed out as conclusions.

- **There are large variations in the compaction properties (w_{opt} and ρ_{max}) among the five types of HMS.**
- **q_u for the five types of HMS was distributed widely at each curing time.**
- **A tendency of q_u to increase with curing time also differed among the five types of HMS.**
- **This variable development of hydraulic nature blurred the effect of compaction efforts on the strength.**
- **M_r also differed among the five types of HMS but there existed a strong linear correlation between the mean q_u and the mean M_r for each of them.**

5. CONCLUSIONS

A possible consequence from this study may be the following:

- **When two base-course are constructed using HMS, they could exhibit a different durability or service life, even if the thickness and compaction degree of the base-course are the same between them.**

> **It would be difficult to determine rationally the thickness of HMS base-course to meet a targeted service life.**

> **One would have no choice but to adopt a conservative thickness, referring to the existing pavement structures with HMS base-course.**