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SELECTION OF RAILWAY BALLAST BASED ON CEMENTING POTENTIAL: A CASE STUDY IN THAILAND

Phitsanu Pholkainuwatra [1], * Sitthiphat Eua-apiwatch [1], and Siam Yimsiri [2]

[1]Department of Civil Engineering, Faculty of Engineering, Burapha University, Thailand;
[2]Sustainable Civil Engineering and Infrastructure Research Unit, Burapha University, Thailand.

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ABSTRACT: The properties of fresh ballasts collected from five quarries around Thailand were investigated in the laboratory. The investigation includes properties specified by the State Railway of Thailand (SRT) for ballast, i.e., rock type, sieve analysis, flat and elongation, and Los Angeles abrasion. Furthermore, cementing value, water absorption, specific gravity, sulfate soundness, and petrographic analysis were also conducted. The obtained rock properties were then compared with the requirements for use as a ballast specified by various national standards, including the Australian Rail Track Corporation (ARTC), the American Railway Engineering and Maintenance of Way Association (AREMA), and the State Railway of Thailand (SRT). The results show that all rocks generally comply with all standards. However, Buriram basalt is considered the best. Saraburi limestone has low abrasion resistance and high cementing value due to its carbonate nature which tends to give higher cementing strength. Igneous and metamorphic rocks usually have plagioclase as their parent mineral which gives low cementing potential. A large abundance of plagioclase in igneous rock, such as Buriram basalt, Nakhon Sawan dacite, and Prachinburi andesite, results in lower cementing values. Rock with high cementing value may hinder its usage as a railway ballast; therefore, the cementation property of ballast by cementing value test, initially suggested by Raymond [1], is strongly recommended as additional criterion in the selection of a ballast.

Keywords: Ballast, Cementing, Rock, Railway

1. INTRODUCTION

One of Thailand's most significant modes of transportation is its railway system. It offers a quick mode of transportation with a reliable and affordable system. More than 4,000 km of track, divided into four routes from Bangkok, are the responsibility of the State Railway of Thailand (SRT), which is also in charge of their operation and engineering. According to Fig. 1, the current routes are North (N), North-East (NE), East (E), and South (S).

In the past, cargo ships would cruise with empty ships and utilize stones as ballast to weigh themselves. It was employed as a railway substructure since these stones needed to be removed and disposed of. Although, the stone has been created specifically for railway uses in the latter stage, it is still referred to as "ballast" until this day [1, 2]. Ballasted tracks are the most common tracks used in the railroad industry. A ballasted track system usually consists of a superstructure (sleeper, fasteners, and rails) and a substructure (ballast, sub-ballast, and subgrade). Ballast can be subdivided into four zones as shown in Fig. 2, i.e. (i) crib - between sleepers, (ii) shoulder - beyond sleeper ends down to bottom of ballast layer, (iii) top ballast - the upper portion of supporting ballast layer, and (iv) bottom ballast - the lower portion of supporting ballast layer [3, 4].

Ballast is generally a selected material of graded crushed rocks used to sprinkle and compact the top layer of a railway substructure in which the sleepers are embedded; however, many other materials have also been used or developed to serve as a ballast [5]. Ballast is often made from crushed rock, especially igneous rock, such as granite or even quartzite metamorphic rocks because it is durable and has suitable drainage characteristics. Ballast should be (i) non-porous and non-absorbent, (ii) resistant to abrasion and corrosion, (iii) durable - not crushed or decomposed under changing weather conditions, and (iv) economically worthwhile.

Ballast has the most important functions as follows [2, 4, 6], (i) transmitting and distributing the load of the track and railroad rolling equipment to the subgrade, thus reducing compressive stress and preventing the subgrade from the exceeding stress [7], (ii) maintaining and restraining track geometry in the lateral, longitudinal, and vertical directions under dynamic loads imposed by railroad rolling equipment and thermal stresses exerted by the rail, (iii) providing adequate drainage for the track and absorption of noise and vibration, (iv) adjustment of the stiffness and elasticity of track structure, and (v) suppression of weed growth on the track. Moreover, the sub-ballast layer must be suitable for preventing the upward migration of fine particles from the subgrade layer into the ballast layer's void.

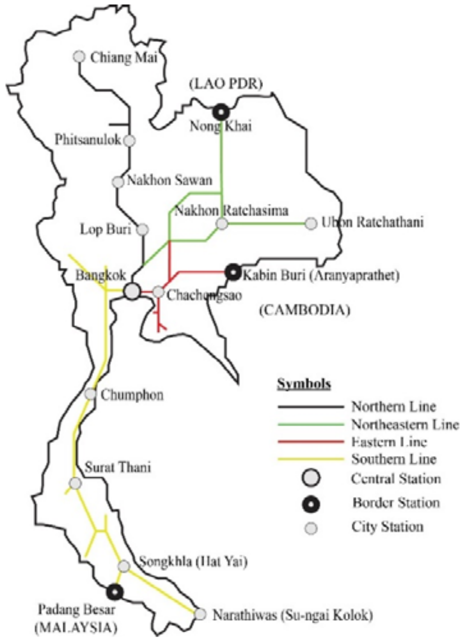


Fig. 1 Existing railway routes in Thailand

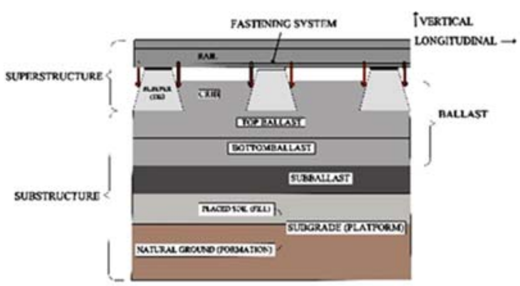


Fig. 2 Railway track structure components [2]

Ballast fouling is a condition when finer particles in the ballast exceed 2% by weight [8]. The fouling of ballast may occur as a result of one or the combination of five different mechanisms, which include (i) fragmentation of ballast, (ii) migration of underlying sub-ballast materials, (iii) surface infiltration of weathered particles and coal droplets, (iv) upward migration of fines from subgrade formations, and (v) sleeper wearing [3]. The effect of ballast fouling is that the contaminated part prevents the ballast from performing its functions. Its severity depends on the amount and cause of contamination. Typical ballast fouling, such as mud pumping or subgrade contamination, occurs continuously and affects train operation by decreasing train speed and capacity (Fig. 3). Therefore, studying ballast cementing can provide valuable data for ballast selection to reduce ballast fouling.

Contamination caused by sedimentary and clay materials is mainly found in the field. Clay alone will not cause attrition; sediment particles can cause attrition. Both clay and sediment interfere with the drainage system of the tracks and, consequently, cause the deterioration of ballast due to poor drainage of the railway tracks. Contamination from fine sand and gravel particles increases the shear strength and the stability of ballast but decreases drainage performance.

Contamination of fine sand and gravel is relatively easy to maintain. Many researchers have conducted experimental studies on fine particle contamination behavior [9-25]. Han and Selig [9] reported that ballast fouling affected settlement and demonstrated that settlement increases with increasing fouling. Budiono [11] presented that the permanent settlement and strength of the track were adversely affected by ballast fouling. Kian et al. [23] developed a formulation of the sleeper design parameters incorporating the effect of sand contamination.

Fig. 3 Mud pumping

2. RESEARCH SIGNIFICANCE

Various countries specify their fundamental qualities of ballast, e.g. the State Railway of Thailand (SRT), the Australian Rail Track Corporation (ARTC), and the American Railway Engineering and Maintenance of Way Association (AREMA). These ballast materials are frequently selected differently depending on the load type, operating environment, rock sources, and foundation conditions, according to the nation's railway authorities [25]. The essential properties required are specific gravity, absorption, particle shape, flakiness index, aggregate compression value (ACV), and Los Angeles abrasion (LAA). Table 1 provides a list of the qualities of ballast that these standards specify.

Table 1 Comparison of ballast standards of different countries

Properties	AREMA	ARTC	SRT
Specific Gravity	2.60-2.65	2.50	-
Absorption	1-2%	-	-
Particle shape	-	<30%	-
Flakiness and Elongation Index	5%	<30%	<30%
ACV	-	25% max	-
LAA	25-40%	25% max	25% max

SRT suggests that only hard rocks must be used as ballast in Thailand. Ballast must not contain any harmful materials which when powdered must not have any cementing force. The "no cementation force" phrase of the SRT standard does not referred to any testing procedures. As far as the Authors are concerned, Raymond's [26] initial recommendation of the ballast cementing value test can be a feasible test approach.

The purpose of this study is to enhance the knowledge of the ballast cementing value test and its application to railway engineering in Thailand. The study aims to assist engineers in determining which type of ballast is most suitable for a specific location or project by considering its cementing potential and physical properties. This consideration may help reducing ballast fouling, which is a problem with railway tracks where the ballast becomes contaminated with dirt, debris, or other material that can reduce the performance and longevity of railway tracks in Thailand.

3. MATERIALS AND METHODS

3.1 Physical and Engineering Properties

Ballasts collected from five quarries in Thailand are used in this study. Fig. 4 shows photos of ballasts, which are gneiss from Chonburi, andesite from Prachinburi, dacite from Nakhon Sawan, basalt from Buriram, and limestone from Saraburi. Table 2 shows the testing program, which includes Los Angeles abrasion, flat & elongation, absorption, specific gravity, sulfate soundness, sieve analysis, and petrographic analysis.

Table 2 Ballast testing program

Properties	Methods
Los Angeles abrasion (LAA)	ASTM C535
Flat & elongation	BS812-105
Specific gravity & absorption	ASTM C127
Sulfate soundness	ASTM C88
Sieve analysis	ASTM D422, D1140
Rock type	Petrographic analysis

a) Chonburi gneiss

b) Prachinburi andesite

(c) Nakhon Sawan dacite

(d) Buriram basalt

(e) Saraburi limestone

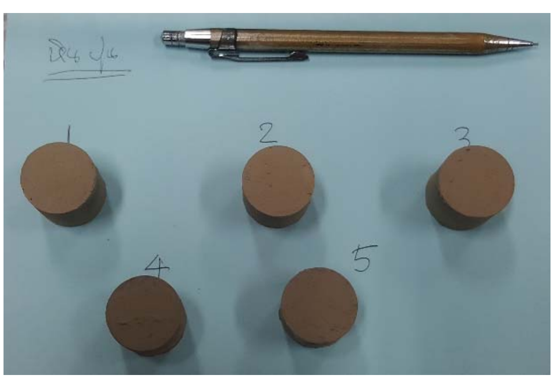
Fig. 4 Ballasts used in this study

3.2 Ballast Cementing Value

The ballast cementing value test is a test of coagulation of the formed rock due to ballast degradation, initially suggested by Raymond [26]. Feng [27] explained the term “cemented ballast” as a condition where the ballast voids are filled with fine particles and bond the coarse aggregate together, resulting in a hard-to-break-up matrix of ballast particles fouling material. This condition can happen when a significant proportion of the fine particles are silt- or clay-size (<0.075 mm) and the ballast has become wet and then dried. The ballast cementing value test has yet to be standardized; therefore, this study employed a ballast cementing value test procedure, as suggested by Boucher and Selig [28].

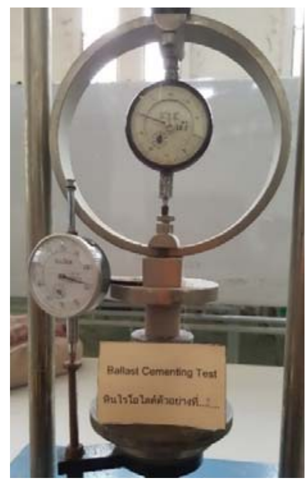
A ballast cementing value test can be conducted by crushing the rock using a LAA machine to obtain the fine particles passing the #200 sieve. After that, a dough is formed using distilled water with its water content above the liquid limit and left overnight. A cylindrical briquette of 25 mm in diameter and 25 mm in height is prepared using a steel cylindrical mold. A pressure of 12.9 MPa is applied to the mold with a compression time of 10 min. The briquette is then extruded, left air-dried for 20 hours, then oven-dried for 4 hours. After that, the samples are placed in the desiccator until they are tested. Fig. 5 shows photos of sample preparation. An unconfined compression test is performed on five prepared samples at a compression rate of 0.0335 in/min to obtain their maximum strength. The cementing value is an average maximum strength of these five tested briquettes. Fig. 6 shows photos of the unconfined compression test on the briquettes.

(a) Apply pressure to a sample



(b) Sample briquettes extruded from the mold

Fig. 5 Sample preparation for ballast cementing value test



(a) Unconfined compression test

(b) Failure of the sample

Fig. 6 Unconfined compression test of a sample

4. RESULTS AND DISCUSSIONS

4.1 Petrographic Analysis

A 0.03-mm-thick thin section of ballast from various sites is prepared and transmitted by a light-polarized microscope. The petrographic analysis results are shown in Table 3. The predominant minerals in Chonburi gneiss are feldspar and quartz. Plagioclase is the main constituent in extrusive igneous rock, such as Prachinburi andesite, Nakhon Sawan decite, and Buriram basalt. Calcite, which is considered a carbonate mineral, is present in Saraburi limestone.

4.2 Physical and Engineering Properties

Sieve analyses are conducted to investigate the particle size distribution of ballast. Particles sizes corresponding to % passing of 10% (D_{10}), 30% (D_{30}), 50% (D_{50}), and 60% (D_{60}) are obtained, and the coefficient of uniformity (C_u=D_{60}/D_{10}) and coefficient of curvature (C_c=D_{30}^2/($D_{10}D_{60}$)) of ballast are then calculated. The sieve analysis result is presented in Fig. 7. The basic ballast properties are presented in Table 4, and the average particle sizes of the ballast are presented in Table 5.

Table 3 Ballast petrographic analysis results

Ballasts	Rock types	Predominant minerals	Percent (%)
Chonburi gneiss	Metamorphic	Feldspar	60
		Quartz	25
		Muscovite	10
		Chlorite	5
Prachinburi andesite	Extrusive igneous	Plagioclase	50
		Chlorite	30
		Olivine	15
		Pyroxene	5
Nakhon Sawan dacite	Extrusive igneous	Plagioclase	40
		Feldspar	25
		Amphibole	20
		Pyroxene	15
Buriram basalt	Extrusive igneous	Plagioclase	55
		Pyroxene	20
		Olivine	20
Saraburi limestone	Sedimentary	Calcite	100

Table 4 Ballast basic properties

Properties	Gneiss	Andesite	Dacite	Basalt	Limestone
LAA (%)	24.1	19.3	8.0	14.1	29.7
Flat & elong. (1:2) (%)	19.8	29.7	33.7	24.1	15.9
Flat & elong. (1:3) (%)	0.8	5.9	5.4	3.2	1.7
Absorption (%)	0.9	0.4	0.2	0.8	0.9
Specific gravity, G_s	2.68	2.70	2.84	2.87	2.68
Sulfate soundness (%)	2.6	1.0	1.2	1.5	2.7

Table 5 Average particle sizes of ballast

Particle size (mm)	Gneiss	Andesite	Dacite	Basalt	Limestone
D_{10}	32.0	30.2	33.0	27.0	30.1
D_{30}	31.0	40.0	40.0	36.0	38.0
D_{50}	45.0	43.0	42.3	40.1	41.0
D_{60}	50.0	44.4	43.3	41.0	42.0
C_u	1.6	1.5	1.3	1.5	1.4
C_c	0.6	1.2	1.1	1.2	1.1

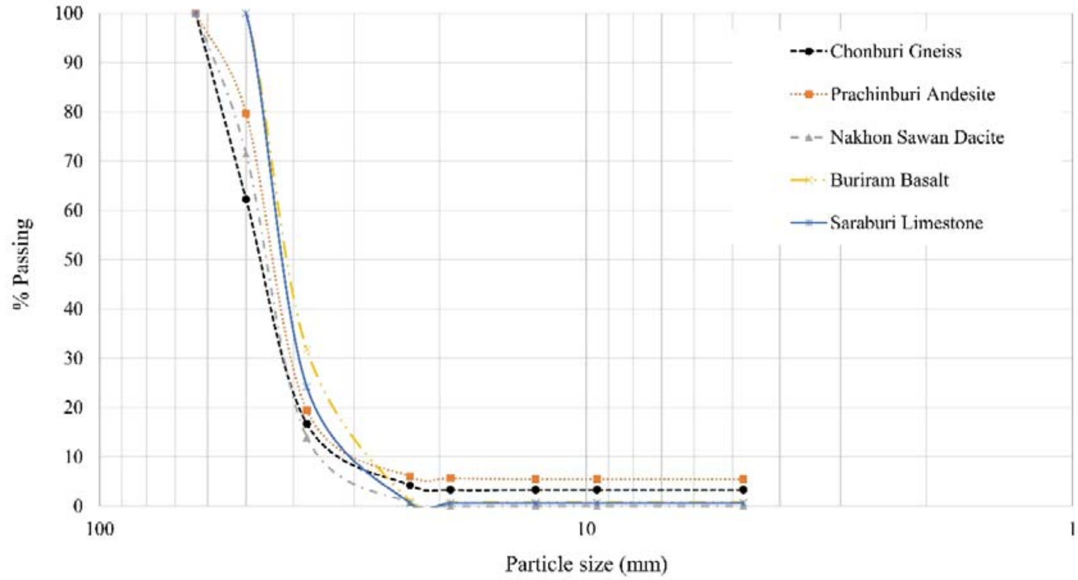


Fig. 7 Ballast particle size gradation results

Sieve analysis results show that the nominal size of ballast (D_{50}) varied from 40.1 to 45.0 mm. Chonburi gneiss contains more larger stones than other ballasts. The coefficient of uniformity (C_u) ranges from 1.3 to 1.6, and the coefficient of curvature (C_c) ranges from 0.6 to 1.2. The grain size distribution of all ballasts can be classified as poorly graded gravel (uniform ballast).

LAA index of tested ballasts ranges from 8.0 to 29.7%, and most of the ballasts comply with the ARTC (LAA<25%), AREMA (LAA 25-40%), and SRT (<25%), except Saraburi limestone with the LAA of 29.7%. ARTC and SRT recommend flat & elongation (1:3) values being smaller than 30%, and only Nakhon Sawan dacite does not comply with these standards. AREMA requires flat & elongation (1:2) values being smaller than 5%, and Nakhon Sawan dacite and Prachinburi andesite do not comply with AREMA requirements. AREMA requires absorption to be smaller than 1%, but the other two standards do not mention about water absorption value. The result shows that all ballasts comply with AREMA. The specific gravity of all ballasts vary from 2.68 to 2.87. The sulfate soundness values of all ballasts pass the requirements of AREMA and SRT.

4.3 Ballast Cementing Value Test Results

Table 6 summarizes ballast cementing value test results. Saraburi limestone has the greatest cementing strength compared to igneous and metamorphic rocks. Cementing strength of Saraburi limestone agrees well with the result from Raymond [26], who reported that the cementing strength of limestone varied from 1.0 to 2.8 MPa with an average of 1.7 MPa. The higher strength may result from the rich in calcite which is a carbonate material.

The abundance of plagioclase in igneous rock, such as Buriram basalt, Nakhon Sawan dacite, and Prachinburi andesite, results in lower cementing strength. Plagioclase is usually found in igneous and metamorphic rocks and has low cementation properties. The lowest cementing strength of Chonburi gneiss may result from the existence of quartz.

Table 6 Ballast cementing values

Rock types	Cementing values (MPa)
Gneiss	0.2
Andesite	0.4
Dacite	0.4
Basalt	0.4
Limestone	2.5

5. CONCLUSIONS

Ballasts recovered from five quarries in Thailand are analyzed in this study. The results show that all rocks, in general, satisfy requirements of various standards, i.e. SRT, ARTC, and AREMA. Nonetheless, Buriram basalt is regarded as the best. Saraburi limestone has the lowest abrasion resistance and the highest cementing value. This is due to it carbonate nature which has a higher cementing strength than igneous and metamorphic rocks. The parent mineral plagioclase, which is frequently found in igneous and metamorphic rocks, has a modest cementation potential. Because of its high cementing value, Saraburi limestone may be less suitable for use as a railroad ballast.

While selecting ballast, it is advised to measure the cementing value of the ballast's cementation characteristics, as suggested by Raymond [26]. If this fine particle has a significant cementing potential, it can bind coarse aggregates and create a matrix of ballast which is difficult to be removed. This hard spot cannot withstand the forces generated by the wheel/rail connection, and when wet, the cemented fines may become brittle and cause mud pumping. The results of these tests may help considering which type of ballast is suitable for a specific project or location.

6. ACKNOWLEDGMENTS

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