

Suitability of Garnet to Grading and Fineness Modulus as Bedding Sand Layer in Concrete Block Pavement

(Kesesuaian Garnet terhadap Penggredan dan Modulus Kehalusan sebagai Lapisan Pasir Dasar dalam Turapan Blok Konkrit)

*MOHD ZAWAWIV AZIZ¹, AZMAN MOHAMED², SURIATI IBRAHIM³
Civil Engineering Department, Politeknik Kuching Sarawak, Malaysia^{1, 3}
Faculty of Civil Engineering, Universiti Teknologi Malaysia, Malaysia²

* Corresponding author: zawawiv@poliku.edu.my

ARTICLE INFO

Article History:

Received 12.08.2022

Accepted 11.10.2022

Published 22.11.2022

Abstract

Currently, highway and road construction use river sand as part of pavement construction. Due to rapid development, the demand for common sand increased and was heavily used in construction. Building constructions also require sand as the material to produce concrete. This is the major factor in increasing the demand for river sand and can increase the price of river sand. There are alternative suggestions by many researchers that use waste materials to replace ordinary sand completely or partially in construction. Therefore, using waste materials such as garnet to replace river sand either partially or fully will conserve our environment and more sustainable solutions. Concrete block pavement (CBP) uses river sand as its bedding sand layer. Therefore, there is the chance of garnet either in part or in full to replace river sand in the pavement constructions. The objective of the study was to determine the effect on the grading curve and the fineness modulus when the various contents of the sand-garnet ratio were used as the pavement-bedding layer. Sieve analysis was conducted to meet the grading requirements according to BS 882 while ASTM C33 was used as the reference in terms of modulus of fineness. The research found that only samples of type 9S1G and 8S2G meet the requirements as a material for the application of pavement base layer to replace part of the sand. In addition, the 9S1G and 8S2G type samples meet ASTM C33, which recommends that the fineness modulus value must be from 2.30 to 3.10 i.e., the fineness modulus value for 9S1G and 8S2G type sample is 2.77 and 2.81 respectively. Therefore, this research suggests that the percentage of garnet replacement for pavement bedding sand layer application is up to 20%.

Keywords: Garnet, concrete block pavement, bedding sand layer

INTRODUCTION

Commonly, there are two types of pavement, rigid pavement, and flexible pavement. Rigid pavement is usually represented by concrete pavement and flexible pavement by asphalt. During the 1970s many developing countries has been introduced to concrete block pavement (CBP). Shackel (2003), in his study, reported that developing countries especially North America experience good growth in CBP manufacturing. Then CBP also spread to the Middle East and Asia.

CBP is made of interlocking blocks that are set on a compacted base of sand or sand and gravel. The performance of CBP is affected by many factors including the block itself and the supporting layers. Much research has been conducted to analyze CBP to get the best performance. Different shapes of blocks, block thickness, laying pattern, bedding sand thickness, etc., may contribute to the different performance of the pavement.

The concrete blocks are laid on the sand called bedding sand and jointed by jointing sand. This composition will receive the load from the surface of the CBP. Blocks and pavers bedded on sand laying course, in common with other forms of flexible paving, deform under traffic as a load (Lilley, 1991). The load will be transferred to the supporting layers through bedding sand. Some of the loads will be transferred to the next blocks through jointing sand. See Figure 1 below:

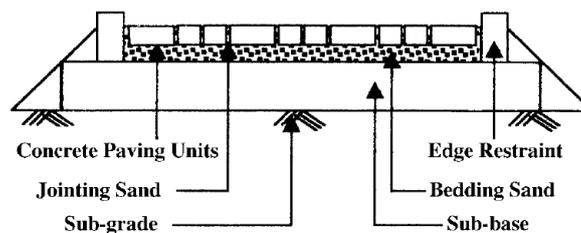


Figure 1. Concrete Block Pavement structure (Panda and Ghosh, 2001)

As the load, forces on the pavers, then it will be transferred to bedding sand, sub-base, and sub-grade.

MATERIALS AND TEST METHODS

Building constructions require sand as the material to produce concrete. Highway and road construction also uses river sand as part of pavement construction. Due to rapid development, the demand for common sand increased and was heavily used in construction. This is the major factor in increasing the demand for river sand and can increase the price of river sand. Nowadays developers have neglected the use of waste materials. There are alternative suggestions by many researchers that use waste materials to replace ordinary sand completely or partially in construction. Replacement of normal sand also has been commercialized in building construction to reduce the construction cost. Therefore, using waste materials such as garnet to replace river sand either partially or fully will conserve our environment, more sustainable solutions and are expected to be more economical in concrete production, and pavement construction.

Garnet is a waste material that exists in the marine industry. Abrasive garnet is used as a cleaning ship's body. However, used garnets then become abundant without appropriate disposal. Concrete block pavement (CBP) uses river sand as its bedding sand layer. Therefore, there is a chance of garnet either in part or in full to replace river sand in the pavement constructions.

The objective of the study was to determine the effect on the grading curve and the fineness modulus when the various contents of the sand-garnet ratio were used as the pavement-bedding layer.

GARNET

Garnet's most commercially important properties are its hardness, inertness, and resistance to degradation. Major uses are as an abrasive and filtration medium. Specific abrasive applications include sandblasting, waterjet cutting, coated abrasives and polishing. Abrasive blasting is the main area of growth because of increasing restrictions on the use of silica and slags for health and safety reasons (Harben, 1999). Figure 2 below shows the difference between garnet and sand in terms of their appearance.



Figure 2. Garnet and Sand

There are different kinds of abrasive garnets which can be divided based on their origin. The largest source of abrasive garnet today is garnet-rich beach sand which is quite abundant on the Indian and Australian coasts and the main producers today are Australia and India (Briggs, 2007). Table 1 below shows the mineral composition of garnet.

Table 1. Mineral composition of Garnet

Mineral Name	Proportion (% Weight)
Almandine Garnet (Fe, Mg) ₃ Al ₂ (SiO ₄) ₃	Greater than 95%
Ilmenite FeTiO ₃	Less than 2%
Calcium Carbonate CaCO ₃	Less than 1.5%
Zircon ZrSiO ₄	Less than 0.2%
Quartz SiO ₂ (Crystalline Silica)	Less than 0.5%

Source: Global Garnet (2013)

The demand for garnet is increased steadily. Most of the usage of garnet is in abrasive applications because of garnet's superior performance and non-hazardous nature (Olson 2005). See Table 2 for the chemical composition of garnet.

Table 2. Chemical composition of Garnet

Chemical Name	Proportion
Silica (SiO ₂)	34 - 38%
Iron (Fe ₂ O ₃) + FeO)	25 - 30%
Alumina (Al ₂ O ₃)	18 - 22%
Magnesium (MgO)	4 - 6%
Calcium (CaO)	1 - 9%
Manganese Dioxide (MnO)	1 - 2%
Titanium Oxide (TiO ₂)	1 - 2%

Source: Global Garnet (2013)

Table 3. Physical and chemical properties

Properties	Characteristics
Mineral:	Almandine
Appearance:	Granular and solid (free-flowing sand / rough grit)
Physical State:	Solid
Colour:	Reddish, brown to pink
Particle Size:	0.05mm – 5 mm
Shape:	Sub-rounded to angular
pH:	Neutral 7.0
Moisture:	Less than 0.2%
Water Solubility:	Insoluble
Acid Solubility (HCL):	1%
Chloride:	Less than 25ppm
Hardness:	7.5 – 8.0 Mohs
Bulk Density:	1900-2400kg/m ³
Reactivity:	Inert

Source: Global Garnet (2013)

Almandine is preferred for most applications because of its superior physical and chemical characteristics (Table 3), which increase the extent to which it can be recycled. Andradite is the only other variety generally considered to be of commercial significance but is regarded as inferior in performance to almandine. Garnets from skarn deposits (commonly andradite) are reported to tend to brittleness, leading to physical breakdown and dusting (Harben & Kuzvart 1996).

BEDDING SAND

Bedding sand should conform to grading requirements for bedding sand. Table 4 shows grading requirements for bedding sand that accordance with British Standard BS 882, 1201, Western Australian Specification AS1141.11, and ASTM C33.

Table 4. Grading (percent passing) requirements comparison for bedding sand

Sieve Size	BS882,1201 BS410	ASTM C33
9.500 mm	100	100
4.750 mm	95 – 100	95 – 100
2.360 mm	80 – 100	85 – 100
1.180 mm	50 – 85	50 – 85
0.600 mm	25 – 60	25 – 60
0.300 mm	10 – 30	10 – 30
0.150 mm	5 – 15	2 – 10
0.075 mm	0 – 10	0 – 1

According to Burak (2006), failure of bedding sand can be structural failure through degradation and saturation due to inadequate drainage. He mentioned smaller particle sizes suspend in water, forming a slurry that lubricates the entire bedding layer. Burak (2006) also recommends choosing bedding sand with correct gradations such as in Table 4. However, these sands will be susceptible to drainage problems if they do not have the hardness to withstand long-term degradation from vehicular wheel loads.

RESULT AND DISCUSSION

Generally, this research was about the maximum percentage of garnet to be added to the bedding sand layer. This research is based on laboratory testing. The laboratory testing aims to compare samples' characteristics of the grading curve and fineness modulus. Therefore, this chapter will present experimental results that consist of sieve analysis and fineness modulus.

SIEVE ANALYSIS

This section discusses the soil passing distribution, grading curve and fineness modulus of samples. Table 5 shows the percentage of sieve analysis soil passing distribution of each sample and minimum and maximum bedding sand layer requirements that accordance with BS 882, 1201: Part 2, 1973.

Table 5. Percentage of sieve analysis sample passing distribution

Dia. (mm)	Soil Passing (%)						Min. Soil Passing (%)	Max. Soil Passing (%)
	10S	9S1G	8S2G	7S3G	6S4G	10G		
10.00	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
5.00	97.3	98.4	98.6	98.1	98.6	100.0	95.00	100.00
2.36	80.9	87.1	87.5	88.8	88.7	100.0	80.00	100.00
1.18	48.9	65.7	64.8	69.4	69.3	100.0	50.00	85.00
0.60	19.1	37.7	37.4	44.8	52.0	99.9	25.00	60.00
0.30	9.9	25.8	26.9	35.5	45.4	95.3	10.00	30.00
0.150	0.6	4.5	8.3	12.5	14.1	36.2	0.00	15.00
Pan	0	0	0	0	0	0	0	0

Table 5 shows that only samples with 10% garnet and 20% garnet are in the passing range of minimum and maximum. The 100% sand used also does not meet the passing distribution requirements of BS882. The garnet size lies in a range mostly below 0.3mm. The grading curve of samples is shown in Figure 3 below:

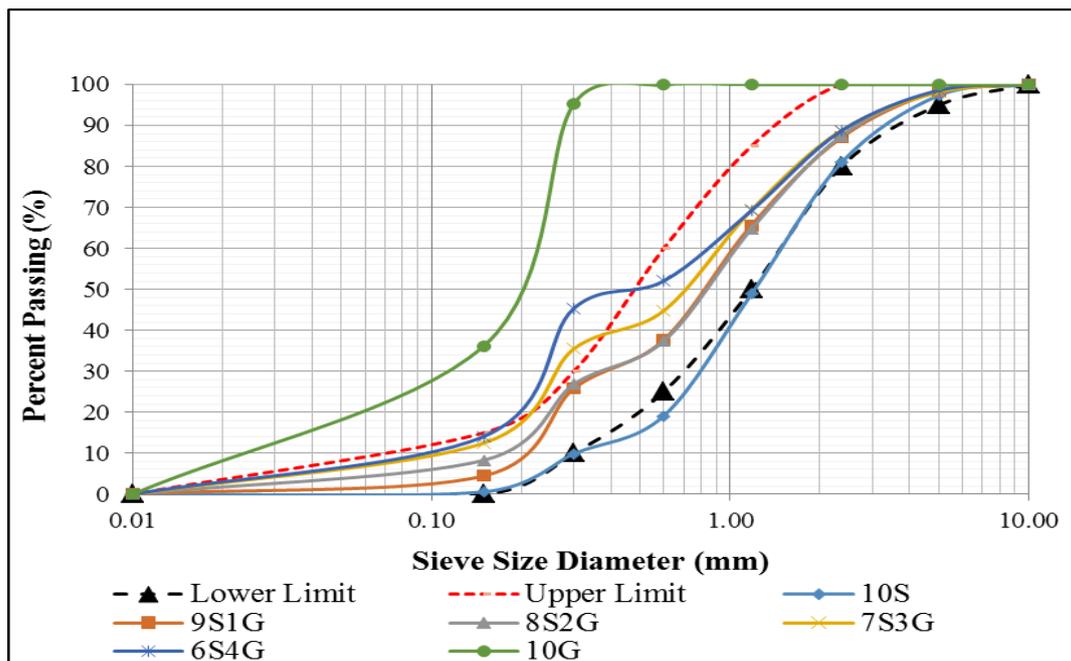


Figure 3. Grading curve of samples

Figure 3 clearly shows that the garnet is out of range of the lower limit and upper limit. Since it contains finer, the addition of 10% and 20% of garnet shows improvements to raw normal sand and makes the grading curve lies within the range of BS882 requirements. Normal sand and garnet have significantly different sizes of particles. As a comparison, the size of particles in each sample shows in Table 6 below.

The fineness modulus of all samples ranges from 0.69 to 3.43 that shows sample sand and garnet have a significant difference in fineness which is garnet is finer than sand. However, sample up to 40% garnet ratio range from 232% to 343%. The fineness modulus of the 100% sand sample is 3.43 not lie within 2.00 to 3.00. So that 100% sand sample was coarser than normal sand discusses in section 2.4.

Table 6. Fineness modulus of samples

Sample Type	Fineness Modulus, k
10S	3.43
9S1G	2.81
8S2G	2.77
7S3G	2.51
6S4G	2.32
10G	0.69

CONCLUSION

The bedding sand layer should conform to grading requirements such as BS882, ASTM C 33 and AS1141.11. The summary of laboratory test results in Table 10, clearly show that only 9S1G and 8S2G accordance with BS882. Even the 9S1G and 8S2G type samples meet ASTM C33 which recommends that the fineness modulus value must be between 2.30-3.10 i.e., the fineness modulus value for 9S1G and 8S2G type samples is 2.77 and 2.81 respectively

The research found that only samples of type 9S1G and 8S2G are suitable as a material for the application of the bedding sand layer to replace part of the sand. This study suggests that the percentage of garnet replacement for bedding sand layers in CBP constructions is up to 20%.

However, this research is only considering the improvement of river sand. Findings of well-graded sand or a different location of river sand are maybe different.

REFERENCES

- American Specification for Testing and Materials. (2003). *Standard specification for concrete aggregates*. Committee American Specification for Testing and Materials. ASTM C33.
- Australian Standard. (1996). Method for sampling and testing aggregates - Particle size distribution by sieving. *Australian Standard*. AS 1141.11.
- Briggs, J., & Giese, T. (2009). *The abrasives industry in Europe and North America: A Market/Technology Report*. Abrasive Engineering Society.
- British Standards Institution. (1973). *Specification for aggregates from natural sources for concrete Part 2*. British Standards Institution, London. BS 882, 1201- 2.
- Burak, R. (2006). Bedding sand selection for interlocking pavements in vehicular applications. *The Engineer View, Interlocking Concrete Pavement Magazine*, 24-31.

- Global Garnet. (2013). *Material safety data sheet*. Retrieved from <http://www.globalgarnet.com.au/wp-content/uploads/Global-Garnet-MSDS.pdf>
- Harben P. W., (1999). *The industrial minerals handbook* (3rd edition). Industrial Minerals Information Ltd, London.
- Harben P.W., & Kuzvart, M. (1996). *Industrial minerals: A global geology*. Industrial Minerals Information Ltd, London.
- Lilley A. A., (1991). *A handbook of segmental paving*. Spon, London.
- Olson D.W. (2005). Garnet (industrial). United States Geological Survey. compiler. Mineral Commodity Summaries 2005, 66-67.
- Panda, B. and Ghosh, A., (2001). Source of Jointing Sand for Concrete Block Pavement. *Journal of Materials in Civil Engineering*, 13(3), pp. 235-237.
- Shackel, B. (2003). *The challenges of concrete block paving as a mature technology*. *Pave Africa*, 12-15.