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The Effect of Fine Aggregate Gradation on the Physical and Mechanical Properties of Paving Blocks

Nico Carlos, [1]Erwin Sutandar[2*], dan Aryanto[3]
[1]*Bachelor Of Civil Engineering Student, Engineering Faculty, Tanjungpura University, INDONESIA*
[2,3]*Civil Engineering Lecturer, Faculty of Engineering, Tanjungpura University, INDONESIA*

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ABSTRACT
In the process of making paving blocks, the problem that often arises is the availability of various variations of sand aggregate gradations. Meanwhile, to improve the quality of paving blocks produced according to SNI-03-0691-1996, the best composition is needed so that the paving blocks produced can have quality according to standards. The results of testing the physical properties carried out on paving blocks showed that the volume weight of paving blocks became lighter with age and the use of coarser sand gradations resulted in a higher weight than paving blocks with finer sand gradations, but for the absorption test for absorption of paving blocks it was not always decreases when using coarser grade sand. The results of testing the mechanical properties carried out on paving blocks found that the compressive strength of paving blocks became stronger with age and the use of coarser sand gradations resulted in higher compressive strength than paving blocks with finer sand gradations, but the wear resistance of paving blocks was not always reduced when using coarser grade sand. The results of checking the quality of paving blocks made with various variations of sand gradations show that there is an increase in quality when using coarse gradation sand. So that the best variation of sand gradation in paving block making is coarse sand gradation.
Keywords: paving blocks, fine aggregate grading, physical and mechanical properties testing

I. INTRODUCTION

According to SNI 03-0691-1996, paving block or concrete brick is a building material made from a mixture of Portland cement, aggregate and water with or without other additives [1]. Paving blocks are an alternative material for pavement on the ground surface. Paving blocks are generally used as pavement, parking lots, sidewalks, yards and parks. Paving blocks are in great demand because they are easy to install, relatively cheap and easy to maintain, and have aesthetic and beauty aspects.

In the process of making paving blocks, the problem that often arises is the availability of various variations of sand aggregate gradations. Meanwhile, to improve the quality of paving blocks produced according to SNI-03-0691-1996, the best composition is needed so that the paving blocks produced can have quality according to standards.

According to Asiacon (2018), sand is one of the most important types of building materials in the construction process. This material or aggregate has the form of granules with a predetermined size. Sand with a coarser gradation has a different function than sand with a finer gradation. It is from these various gradations of sand that the aggregate size and function of sand differ. In a sense, sand is fine aggregate with varying sizes and is grouped based on aggregate gradation [2].

According to SNI 03-2834-2000, there are several variations of the gradation of sand used for construction materials, namely as follows [3]:

1. Gradation number 1, namely the gradation of coarse sand.
2. Gradation number 2, namely the medium sand gradation.
3. Gradation number 3, namely the gradation of rather fine sand.
4. Gradation number 4, namely fine sand gradation.

According to SNI 03-0691-1996, there are several requirements for the quality of the paving blocks used, namely as follows [1]:

Table 1 Paving block quality requirements

Grade	Compressive Strength (MPa)		Wear (mm/min)	Resistance	Absorption (%)
	Average	Min.	Average	Min.	Max.
A	40,0	35,0	0,090	0,103	3
B	20,0	17,0	0,130	0,149	6
C	15,0	12,5	0,160	0,184	8
D	10,0	8,5	0,219	0,251	10

Source: SNI 03-0691-1996

Based on previous research conducted by Yon Fajri, Riad Syech, and Sugianto (2016) in their research entitled "Determination of Paving Block Quality Based on Physical Properties of Mixed Sand and Cement Variations". It was concluded that the best composition for making paving blocks with the best quality is 1,0 cement (Pc) :1,0 sand (Ps) [4]. After conducting a trial of a mixture of 1,0 cement (Pc): 1,0 sand (Ps) it was found that the quality was too high so that the composition used in this study was 1,0 cement (Pc) : 2,0 sand (Ps).

Based on Tjokrodimulyo (2007) in the book "Concrete Technology", it was concluded that the higher the cement water factor (FAS) resulted in a decrease in the quality of concrete strength. Meanwhile, the lower the FAS value, the more difficult the concrete is to compact, so that a lower FAS value does not always increase the strength of the concrete. So that an optimal FAS value is needed so that it can produce maximum concrete strength, generally the FAS value used in the manufacture of normal concrete is a minimum of 0,4 and a maximum of 0,65 [5]. So the composition used in this study was 1,0 cement (Pc): 2,0 sand (Ps) with a water-cement factor of 0,4.

Based on previous research conducted by Fajar ImawanAkhmad (2022) in his research entitled "The Effect of Using Corn Gravel as a Partial Substitute for Sand in Paving Blocks". It was concluded that sand substituted with gravel at a variation of 10% by weight of sand is the optimum percentage of gravel [6]. So that in this study the percentage of fine aggregate substituted with gravel was 10%, so the composition used in this study was 1,0 cement (Pc) :1,8 sand (Ps) : 0,2 crushed stone (Pb) with cement water factor of 0,4.

Based on previous research conducted by Faisal and Gatot Setya Budi (2022) in their research entitled "The Effect of Using Fly Ash and Bottom Ash on the Physical and Mechanical Properties of Making Paving Blocks". It was concluded that the composition of 1,0 cement (Pc) :0,5 crushed stone (Pb) : 3,0 sand (Ps) with a FAS of 0,25 produced paving blocks that had B quality [7]. So that in this study with a composition of 1,0 cement (Pc) :1,8 sand (Ps) : 0,2 crushed stone (Pb) with a FAS of 0,4 it is hoped that it will be able to produce paving blocks that have quality A in accordance with SNI 03 -0691-1996, and this research leads to variations in fine aggregate gradations to improve the quality of paving blocks produced.

RESEARCH METHODS

In general, the research carried out belongs to the library and experimental research methods, because before conducting experiments it is necessary to collect information through the literature and applicable standards, and by carrying out experiments it can produce objective truth supplemented by facts and evidence. The purpose of this study was to determine the physical and mechanical properties of paving blocks due to fine aggregate gradation based on the applicable requirements.

At the beginning of the study an analysis of the paving block mix was carried out to determine the characteristics of the material in the mix design. The materials used are portland composite cement (PCC), coarse graded sand, medium graded sand, slightly fine graded sand, fine graded sand, and crushed stone. Material analysis carried out was analysis of organic content of fine aggregate, analysis of silt content of fine aggregate, analysis of water content of fine aggregate, analysis of specific gravity and water absorption of fine aggregate, analysis of fine aggregate gradation, analysis of unit weight of fine aggregate, analysis of moisture content of coarse aggregate, analysis specific gravity and water absorption of coarse aggregate, analysis of coarse aggregate gradation, analysis of unit weight of coarse aggregate, analysis of wear and tear of coarse aggregate, analysis of specific gravity of cement, and analysis of unit weight of cement. After doing the

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material analysis, the next step is to plan the mix (mix design).

Picture 1 Paving block Research Flowchart

The equipment to be used in making paving blocks with a size of 210 x 105 x 80 mm are:

- Material analysis equipment, such as:
  - Organic plates.
  - Container.
  - Measuring cup.
  - Sieve shaker machine.
  - Aggregate filter.
  - Drying ovens.
  - Pycnometer.
- Digital scales.
- Compression testing machine.
- Cement spoon.
- Paving block mixer machine.
- Paving block press machine.

Material Analysis

Material analysis aims to determine the physical properties of the materials used in research, especially when doing mix design. By conducting material analysis, it is possible to determine the amount of material required in designing the mix design. The following is a material analysis carried out:

Fine Aggregate

The fine aggregate used in this study is river sand which is a mandatory material for testing the properties and characteristics of aggregates. The following tests were carried out:

- Fine aggregate organic rate
- Analysis of fine aggregate silt rate
- Fine aggregate absorption analysis
- Analysis of specific gravity and water absorption
- Fine aggregate gradation analysis
- Analysis of the weight volume of fine aggregate

Coarse Aggregate

The coarse aggregate used in this study is crushed stone 0,5 which is a mandatory material for testing the properties and characteristics of the aggregate. The following tests on coarse aggregate were carried out:

- Coarse aggregate moisture analysis
- Analysis of specific gravity and water absorption
- Coarse aggregate gradation analysis
- Coarse aggregate weight volume analysis
- Coarse aggregate wear resistance checking

Cement

The composite portland cement used in this study was conch brand cement. This type of cement can be purchased from building materials stores located in the Pontianak city area. Observation of chemical properties and physical properties was not carried out in this study because conch brand cement complied with the requirements contained in SNI 7064-2014 [8]. The following tests on cement were carried out:

- Analysis of cement specific gravity
- Analysis of cement volume weight

Water

The water used must meet several criteria including visually and content must meet the requirements of SNI 03-6861.1-2002 [9]. The water used is water from the Pontianak PDAM which meets the requirements according to the Indonesian Concrete Regulation (PBI-71) [10]. So for paving block research, the chemical content in water was not tested.

Paving Block Testing

Visual Checking

A visual inspection is carried out on the paving blocks with the specifications that must be met, namely having a flat surface, no defects and cracks, and the corners and ribs are not easily straightened by the strength of your fingers. As well as for paving block dimensions, it must have a minimum thickness of 60 mm with a thickness tolerance of + 8%.

Pemeriksaan Berat Volume

Checking the volume weight is the measurement of weight per unit volume of an object. The weight of an object is directly proportional to the weight of each volume. However, the volumetric weight of an object is inversely proportional to the porosity of the object. To calculate the volume weight, the following equation is used:

$$BV = \frac{w}{v} \quad \text{...(1)}$$

Keterangan :
BV = Volume weight (kg/m3)
W = Weight of test object (g)
V = Volume of test object (m3)

Pemeriksaan Kuat Tekan paving block

According to SK SNI S-14-1989-F regarding testing the compressive strength of concrete, the compressive strength of concrete is the magnitude of the load per unit area that causes a concrete specimen when loaded with a certain compressive force that is loaded by a press machine [11]. According to the theory of concrete technology, the factors that affect the strength of concrete are density, type of cement, age of concrete, water-cement factor, aggregate properties, and amount of cement. Measurement of the compressive strength of paving blocks refers to SNI 03-0691-1996 with the following equation [1] :

$$KT = \frac{P}{L} \quad \text{..(2)}$$

Keterangan :
KT = Compressive strength (N /mm2)
P = Compressive load (N)
L = Pressure area (mm2)

The average compressive strength of the paving block samples is calculated by the following equation:

$$KT_R = \frac{\Sigma KT}{\Sigma Sample} \quad \text{...(3)}$$

Absorpstion Checking

Absorption or absorption of water is the ratio of the weight of water absorbed by the pores of the test object, with the resulting units expressed in units of percent. The amount of water absorption is strongly influenced by the porosity found in the test object. If the porosity value of the paving block is large, the absorption of water will be greater, and will reduce the durability of the brick. Large porosity values generally occur due to the inaccurate composition and quality of the paving block aggregates. To calculate the amount of absorption of paving blocks, the following equation can be used:

$$Wa = \frac{Mj - Mk}{Mk} \times 100\% \quad \text{...............................(4)}$$

Keterangan :
Wa = Water absorption (%)
Mj= Mass of object in saturated condition (g)
Mk = Mass of dry matter (g)

Wear Resistance Testing

Paving block wear resistance is the resistance of the paving block surface layer to continuous friction. During the wear resistance testing process, the paving blocks will be weighed before and after the wear resistance test, then the paving blocks will be rubbed using a piece of tubeless motorcycle tire for 5 minutes at a speed of 20 rubs per minute so that the total rubs made are 100 rubs, then cleaned dust and debris on the paving block surface using a brush, then measure the surface area of each paving block that has been rubbed using a slide rule. According to SNI 03-0028-1987 to calculate the value of wear resistance possessed by paving blocks is as follows [12]:

$$\text{Wear resistance} = \frac{A \times 10}{BJ \times L \times W} \quad \text{...............................(5)}$$

Keterangan :
A = Difference in weight of paving blocks before and after they are worn
BJ = Specific gravity of paving block
L = Wear surface area (cm2)
W = Wear time (5 minutes)

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II. RESULTS AND DISCUSSION

Based on the results of the tests carried out, the results obtained are as follows:

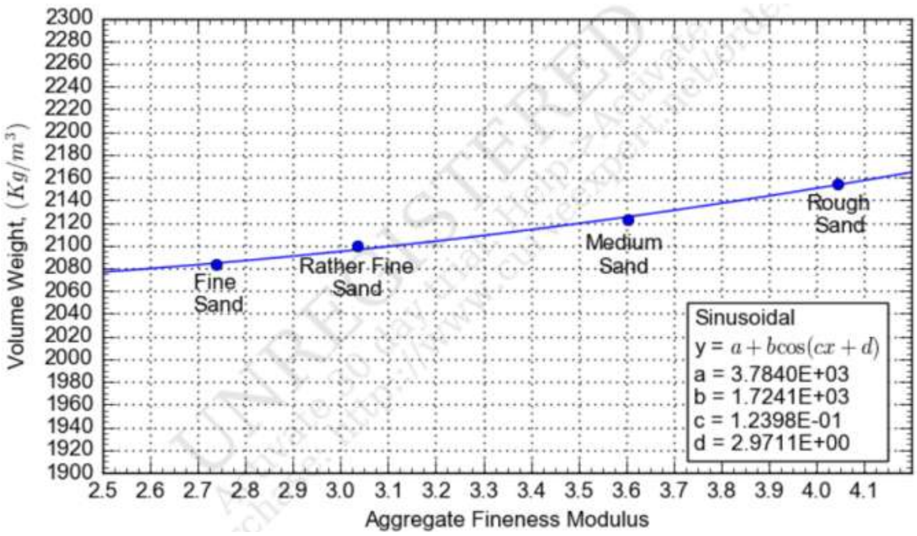
Table 2 Results of Examination of Paving Block Thickness

Variation	Average Thickness (mm)	Thickness Plan (mm)
Rough Sand	81,675	80
Medium Sand	80,045	80
Rather Fine Sand	78,818	80
Fine Sand	81,079	80

From the table above, it is found that the thickness of paving blocks for all variations of sand gradations has conditions for flat, uncracked, and rough areas. As for the ribs that are angled, not sharp, and strong. As well as the thickness that meets the thickness plan and paving block quality requirements.

Table 3 Results of Paving Block Volume Weight & Fine Aggregate Fineness Modulus Examination

Variation	Average Volume Weight (kg/m^3)	Aggregate Fineness Modulus
Rough Sand	2154,283	4,043
Medium Sand	2122,806	3,604
Rather Fine Sand	2099,419	3,035
Fine Sand	2082,901	2,740



Picture 2 Graph of Average Weight-Volume Relationship between Paving Blocks and Aggregate Fineness Modulus

The table and graph above shows that paving block variations of fine sand gradations that have the smallest aggregate fineness modulus produce paving blocks with the smallest volume weight, but the volume weight becomes larger for paving block variations of rather fine sand, medium sand, and coarse sand. which has a finer modulus greater than the variation of fine sand due to the composition of the material used, namely fine aggregate with a coarser gradation which has a larger aggregate fineness modulus has a higher unit weight than fine aggregate with a finer gradation which has a smaller

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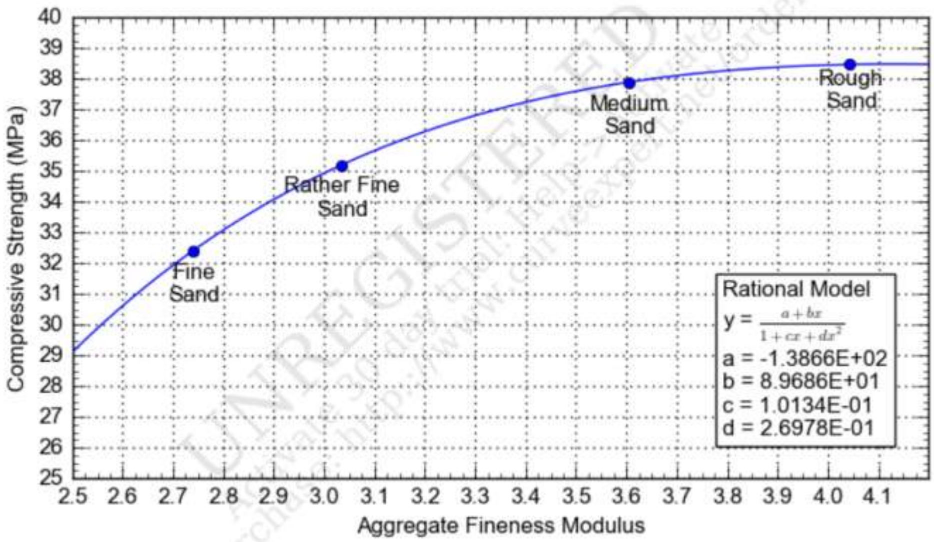
aggregate fineness modulus, so that it can be concluded that the volume weight of paving blocks with fine aggregate fineness modulus is directly proportional and does not cause significant changes to the volume weight of paving blocks.

Table 4 Examination Results of Compressive Strength of paving blocks & Fine Aggregate Fineness Modulus

Variation	Average Compressive Strength (MPa)	Aggregate Fineness Modulus
Rough Sand	38,481	4,043
Medium Sand	34,570	3,604
Rather Fine Sand	31,334	3,035
Fine Sand	28,047	2,740

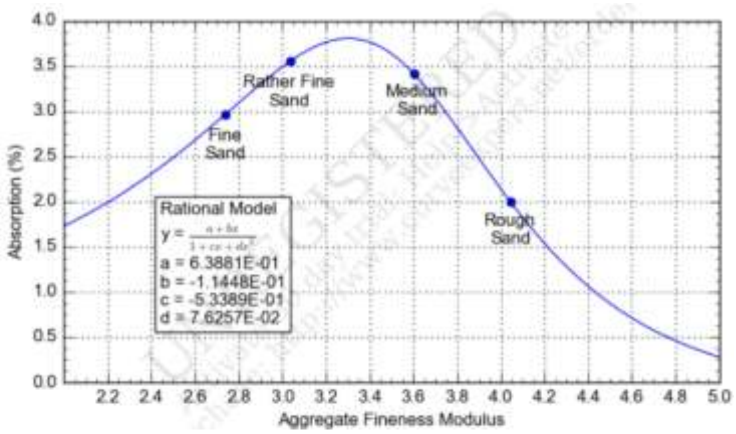


Picture 3 Graph of Average Compressive Strength Relationship between paving blocks and Aggregate Fineness Modulus

The table and graph above shows that paving block variations of fine sand gradations that have the smallest aggregate fineness modulus produce paving blocks with the smallest compressive strength, but the compressive strength becomes larger for paving block variations of rather fine sand, medium sand, and coarse sand which has a greater aggregate fineness modulus because the distribution of aggregate sizes is increasingly diverse resulting in voids in paving blocks becoming smaller and can increase the density of paving blocks. So it can be concluded that the compressive strength of paving blocks with fine aggregate fineness modulus is directly proportional, and causes a significant increase in paving block compressive strength, but as the aggregate fineness modulus increases, the increase in paving block compressive strength becomes smaller and insignificant.

Table 5 Examination Results of Paving Block Absorption & Fine Aggregate Fineness Modulus

Variation	Average Absorption (%)	Aggregate Fineness Modulus
Rough Sand	2,000	4,043
Medium Sand	3,409	3,604
Rather Fine Sand	3,550	3,035
Fine Sand	2,965	2,740

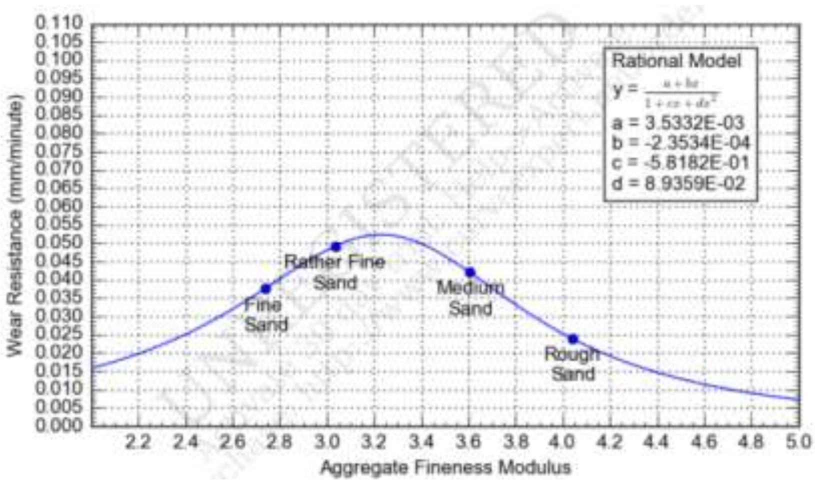


Picture 4 Graph of Average Absorption of Paving Blocks with Aggregate Fineness Modulus

From the tables and graphs of the absorption test results above, the equation $y = \frac{0,639-0,114x}{1-0,534x+0,076x^2}$ and R^2 = 1,000 indicates that paving block variations of coarse sand gradations that have the largest aggregate fineness modulus have absorption is the smallest, absorption becomes greater for paving block variations of medium sand and rather fine sand which have a smaller fineness modulus, but for paving block variations of fine sand which has the smallest fineness modulus there is a decrease in the absorption of paving blocks so that it can be concluded that absorption paving blocks due to variations in fine aggregate fineness modulus are not directly proportional and do not cause significant changes to the absorption of paving blocks. So that paving blocks with coarse sand gradation variations are categorized in quality A, paving blocks with medium sand gradation variations are categorized in B quality, paving blocks with rather fine sand gradation variations are categorized in B quality, paving blocks with fine sand gradation variations are categorized in A quality.

Table 6 Examination Results of Paving Block Wear Resistance & Fine Aggregate Fineness Modulus

Variation	Average Wear Resistance (mm/min)	Aggregate Fineness Modulus
Rough Sand	0,024	4,043
Medium Sand	0,042	3,604
Rather Fine Sand	0,049	3,035
Fine Sand	0,038	2,740



Picture 5 Graph of Average Wear Resistance of Paving Blocks with Aggregate Fineness Modulus

From the table and graph of the wear resistance test results above, the equation $y = \frac{3{,}533\times10^{-3}-2{,}353\times10^{-4}}{1-0{,}582x+8{,}936\times10^{-2}x^2}$ dan R^2 = 1,000indicates that the paving block variation of coarse sand gradation which has the largest aggregate fineness modulus has the smallest wear resistance, wear resistance becomes greater for paving block variations of medium sand and rather fine sand which has a smaller fineness modulus , however, for paving block variations of fine sand which has the smallest fineness modulus, there is a decrease in the wear resistance of paving blocks, so it can be concluded that the wear resistance of paving blocks due to variations in the fineness modulus of fine aggregate is not directly proportional and does not cause significant changes to the wear resistance of paving blocks. So that the paving blocks of all variations of sand gradations have met the required quality and are categorized in quality A.

Results of Paving Block Quality Analysis

Based on visual testing and paving block thickness, it can be concluded that for all variations, paving blocks have flat, uncracked, and rough areas. As for the ribs that are angled, not sharp, and strong. As well as the thickness that meets the thickness plan and paving block quality requirements.

Based on the unit weight test, it was found that the volume weight of paving blocks with gradations of coarse sand, medium sand, slightly fine sand, and fine sand was lighter at 28 days, and paving blocks with variations in coarse sand gradations had a higher unit weight at 28 days. compared to paving blocks with finer variations of sand gradations.

Based on the results of the 28day average compressive strength test obtained from various gradations, it shows that the paving block gradation of coarse sand has the smallest compressive strength at the age of 28 days with a compressive strength of 38,481 MPa so that it is classified as A quality, medium sand gradation has the smallest compressive strength at 28 days old with a compressive strength of 34,570 MPa so that it enters B quality, rather fine sand gradations have the smallest compressive strength at 29 days of age with a compressive strength of 31,334 MPa so that it enters B quality, and fine sand gradations have the smallest compressive strength at 30 days with a compressive strength of 28,047 MPa so that it is classified as B grade.

Based on the average absorption of various variations of paving blocks, it shows that variations of coarse sand gradations have an average absorption of 2,000% so that paving blocks enter grade A, variations of medium sand gradations have an average absorption of 3,409% so that paving blocks so that paving blocks enter into quality B, variations in the gradation of rather fine sand have an average absorption of 3,550% so that paving blocks so that paving blocks enter quality B, variations in gradations of fine sand have an average absorption of 2,965% so that paving blocks become paving blocks get into grade A.

Based on the average wear resistance of the various variations, it shows that the coarse sand gradation variation has a wear resistance of 0,041 mm/minute so that it enters quality A, the medium sand gradation variation has a wear resistance of 0,073 mm/minute so it enters A quality, the sand gradation variation rather fine has a wear resistance of 0,076 mm/minute so that it is included in quality A, variations in gradations of fine sand have a wear resistance of 0,055 mm/minute so that it is included in quality A.

Based on various tests on paving blocks, for coarse sand gradations they produce paving blocks with A quality, for medium sand gradations they produce B quality paving blocks, for rather fine sand gradations they produce B quality paving blocks, for fine sand gradations they produce B quality paving blocks.

III. CONCLUSION

Based on the initial hypothesis that various quality checks for paving blocks made with various variations of sand gradations show that there is an increase in quality when using coarse gradation sand and a decrease in quality when using finer gradations of sand. So that the best variation of sand gradation in paving block making is coarse sand gradation.

Based on the initial hypothesis that physical properties tests were carried out on paving blocks, namely visual inspection, volume weight testing, and absorption testing. It was found that the paving blocks met the visual requirements, the volume weight of the paving blocks became lighter with age and the use of coarser sand gradations resulted in a higher weight than paving blocks with finer sand gradations, but for the absorption test it was not in accordance with the initial hypothesis, namely Paving block absorption is not always reduced when using coarser graded sand.

Based on the initial hypothesis that the mechanical properties test was carried out on paving blocks, namely compressive strength testing, and wear resistance testing. It was found that paving blocks met the compressive strength requirements, the compressive strength of paving blocks became stronger with age and the use of coarser sand gradations resulted in higher compressive strength than paving blocks with finer sand gradations, but the wear resistance test was not in accordance with the initial hypothesis is that the wear resistance of paving blocks does not always decrease when using coarser gradation sand.

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