Utilization of Silica Sand and Gravel from Indarung Limestone Waste as Aggregate Substances for Rigid Pavement

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Abstract. Roads have a very important role in advancing national development, structures made of concrete are very susceptible to cracking due to the brittle nature of the material and the nature of concrete that is strong against pressure, but weak against pulling. And the utilization of waste material as substitution of aggregate in concrete has been increasing nowadays. Therefore in this research, the use of silica sand and gravel from Indarung limestone waste were investigated. The purpose of this study is to determine the utilization of silica sand and gravel affect the compressive strength of the concrete as a substitution of coarse aggregates and fine aggregates in concrete mixtures in order to increase the value of compressive strength and bending strength in concrete, especially for rigid pavements. The method in this research applies experimental methods, the tests carried out in this study include material testing, compressive strength testing and concrete bending strength testing. Testing is carried out referring to the American Standard Testing and Materials (ASTM). Based on the experimental results; the highest compressive strength value of concrete obtained in the 3rd concrete variation with a concrete mixture of 100% Silica sand + Natural gravel + Sikament NN with a value of 41.14 MPa. For the optimum bending strength value obtained in a concrete mixture with the 4th variation, namely 100% Natural sand + Silica Gravel + Sikament NN with a value of 1.6 MPa. Based on the results in road planning, the 4th concrete variation was used as a variation that will be applied on the basis of its optimum bending strength value and a compressive strength value that exceeds the design compressive strength which is 32.36 MPa. The planning for rigid pavement on Jalan Simpang Anak Aia – Fly Over Minangkabau International Airport STA 22 + 800 to STA 22 + 800 by using the MDP2017 method, with the pavement thickness of 27.5 cm.

Keywords: concrete · pavement · silica · strength

1 Introduction

Roads have a very important role in advancing national development. In recent years, the use of rigid pavement for roads has become more common. Structures made of

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concrete are very susceptible to cracking due to the brittle nature of the material as well as the properties of concrete that are strong against pressure, but weak against tensile. The weak tensile properties cause concrete to crumble or break without changing shape when the maximum stress is reached. Structures made of concrete are very susceptible to cracking due to the brittle nature of the material as well as the properties of concrete that are strong against pressure, but weak against tensile. The weak tensile properties cause concrete to crumble or break without changing shape when the maximum stress is reached [1].

The use of silica sand is often used for metallurgical sand, which is sand produced from the processing of a mineral or metal from silica sand. Silica sand is widely used in industrial activities in which its use is used according to its characteristics, including being used as glass making production, ceramic manufacturing, clean water production filters, concrete casting, sandblasting to clean iron rust crusts such as machines, pipes, plates and so on. In concrete casting fine aggregate or silica sand is used as the main element in the manufacture of fresh concrete in the batching plant, in addition to coarse aggregate, cement and water and additives [2].

Due to these limitations, it was decided that the supply of silica from the mine was only to meet the needs of the Indarung plant, while at the factory in October 2016 it was decided to use Pozzolan as a substitute for the limited silica from the mine. From this data it can be concluded that the use of silica is lacking in the cement manufacturing process and becomes an unused material. Indarung factory waste can be a benefit to the community because it is not every region has silica material. Silica material can be used as an alternative to aggregate replacement for mixed materials in concrete so that it can open up job opportunities for the community and be able to improve the community's economy.

In this study, further research was conducted on the extent to which silica sand and gravel affect the compressive strength and bending strength of concrete as a substitute for coarse aggregate and fine aggregate in concrete mixes [3] in order to increase the compressive strength and flexural strength values of concrete, especially for rigid pavements.

2 Research Methodology

The method in this research applies the experimental method. The tests carried out in this study include material testing [4], compressive strength testing and concrete flexural strength testing. Tests were carried out referring to the American Standard Testing and Material (ASTM) as well as some previous research literature that has been carried out in Concrete Laboratory, Department of Civil Engineering, Politeknik Negeri Padang. Silica material used in this research are from Indarung limestone waste, while fine and coarse aggregate are from natural aggregate in West Sumatera. This research was conducted to obtain the composition of the silica aggregate mixture as an additional ingredient in concrete, where the results of this study are the results of compressive strength, flexural strength of concrete and for rigid pavement design. In this research, there are five types of variations in the percentage of silica aggregate that will be added to the concrete mixture, where the five variations include, 100% natural sand + natural gravel, 100% natural sand

Table 1. Slump test result (cylinder samples)

Samples	H1	H2	H3	Average
100% fine aggregate + coarse aggregate	9	9.5	10	9.5
100% fine aggregate + coarse aggregate + sika	11	10.5	10	10.5
100% silica sand + coarse aggregate + sika	11.5	11	10	10.8
100% fine aggregate + silica gravel + sika	flow	flow	flow	0.0
100% silica sand + silica gravel + sika	8	8	8	8.0

Table 2. Slump test result (beam samples)

Samples	H1	H2	H3	Rata-Rata
100% fine aggregate + coarse aggregate	9.5	10	11	10.2
100% fine aggregate + coarse aggregate + sika	9	8	12	9.7
100% silica sand + coarse aggregate + sika	9	11.5	10	10.2
100% fine aggregate + silica gravel + sika	flow	flow	flow	0.0
100% silica sand + silica gravel + sika	flow	flow	flow	0.0

+ natural gravel + Sikament NN, 100% silica sand + natural gravel + Sikament NN, 100% natural sand + silica gravel + Sikament NN and 100% silica sand + silica gravel + Sikament NN. The amount of Sikamen used is about 2.3%. [5]. Mix design method for high strength concrete is based on ACI 211. 4R-93 Guided for Selecting Proportions for High Strength Concrete. And for rigid pavement design is based on MDP2017.

3 Results and Discussion

3.1 Fresh Concrete Testing

The results of the slump and weight content tests with silica sand and gravel as aggregate substitutes in concrete mixes with cylinder samples can be seen in Table 1 and beam samples can be seen in Table 2.

The slump value has a plan slump limit of 80–120 mm. [6]. However, in the manufacture of the mixture there are several conditions that are caused by the addition of additives, namely Sikamen NN, which gives watery properties to the concrete but is fast in the concrete setting process, so that when the concrete slump test is carried out, the flow concrete slump is obtained.

3.2 Compressive Strength Testing

Some variations of silica sand and gravel as aggregate substitution in concrete mixtures for compressive strength testing are as follows:

Table 3. 28-day compressive strength.

Samples	Weight of Sample (kg)	Force (kN)	Compression strength (MPa)	Average of compressive strength (MPa)
1	12.320	306.59	17.36	17.28
	12.245	299.63	16.96	
	12.545	309.47	17.52	
2	12.41	478.62	39.73	36.10
	12.5	439.68	36.49	
	12.565	386.65	32.09	
3	12.52	483.91	40.16	41.14
	12.50	488.41	40.54	
	12.55	514.76	42.73	
4	12.745	451.88	37.51	32.36
	12.870	374.37	31.07	
	12.885	343.22	28.49	
5	13.255	301.40	25.02	26.52
	12.880	338.48	28.09	
	12.895	318.56	26.44	

1. 100% fine aggregate + coarse aggregate
2. 100% fine aggregate + coarse aggregate + sika
3. 100% silica sand + coarse aggregate + sika
4. 100% fine aggregate + silica gravel + sika
5. 100% silica sand + silica gravel + sika

The results of testing the compressive strength of sand concrete and silica gravel as aggregate substitution at the age of 28 days. [7]. Can be seen at Table 3.

From the graph in Fig. 1, it can be seen that the highest compressive strength value is found in 3rd variation (100% silica sand + coarse aggregate + sika) with an average compressive strength value of 41.14 MPa, then concrete with 2nd variation (100% fine aggregate + coarse aggregate + sika) with a compressive strength of 36.10 MPa and concrete 4th variation (100% fine aggregate + silica gravel + sika) with a concrete compressive strength value of 32.36 MPa, so that it can meet the compressive strength plan in this study, namely fc ’30 MPa.

3.3 Flexural Strength Testing

The results of the flexural strength test of sand concrete and silica gravel as aggregate substitution at the age of 28 days. [8], can be seen in Table 4.

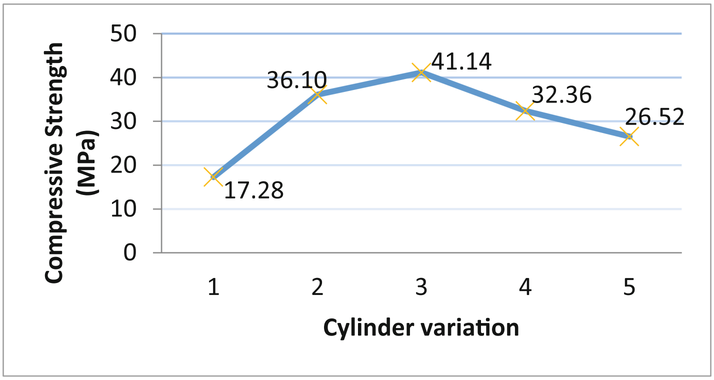

Fig. 1. Compressive strength

Table 4. 28-day flexural strength.

Variation	Weight of Sample (kg)	Notation (mm)			Compressive strength (kN)	Flexural strength (MPa)
		l	b	h		
1	31.660	450	150	154	13	0.7
	31.190	450	152	153	14.4	0.8
2	33.065	450	153	153	22.1	1.2
	32.930	450	153	153	21.1	1.1
3	32.915	450	152	153	20.7	1.1
	32.625	450	150	153	21.2	1.2
4	32.905	450	150	150	27.4	1.5
	33.025	450	150	150	28.4	1.6
5	29.215	450	150	150	26.3	1.4
	29.360	450	150	150	32.6	1.8

From the graph in Fig. 2, it can be seen that the highest flexural strength value is found in 4th variation (100% Silika gravel + fine aggregate + Sikament NN) with an average compressive strength of 1.6 MPa.

3.4 Crack Analysis of Test Objects

The following are some of the results of the cracking pattern of 28-day-old cylindrical specimens can be seen in Fig. 3 and Table 5.

Based on Table 5. it can be seen that the average crack pattern for variations 1 to 4 is type 2. Crack pattern type 2 is a crack pattern starting from the top surface but not reaching the bottom surface of the specimen. Cracking pattern type 1 to type 5 is a well-defined pattern and the specimen has reached its compressive capacity limit. [9].

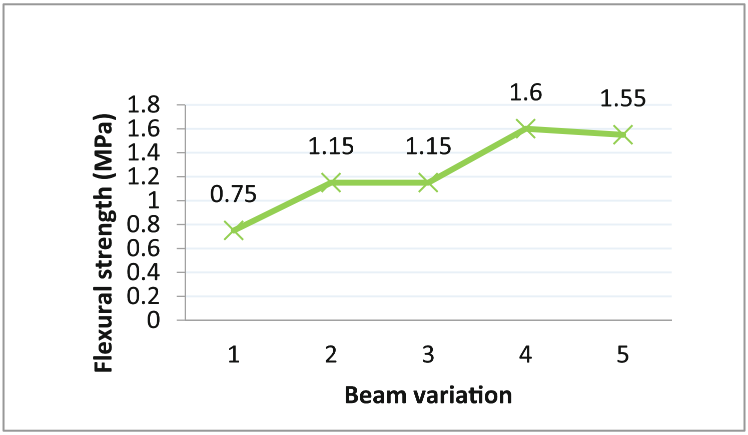

Fig. 2. Concrete flexural strength

Fig. 3. Crack pattern of cylinder

The crack pattern of the beam test specimens during the flexural test for variations 1, 2 and 3 is type 1 where the crack is at 1/3 of the center span, while variations 2 and 4 are type 2 where the crack is outside 1/3 of the center span and the fracture line is at < 5% of the span illustrated as in Fig. 4. The crack pattern for type 1 and type 2 flexural strength values can be used. [8]. The role of silica sand and gravel can be seen in increasing the compressive strength of normal concrete after the addition of silica material, it also impact in resisting cracking in cylindrical test specimens can be seen from the shape of the collapse which is increasingly conical upwards along with the increase in the variation in the use of silica aggregate material. This proves that the silica aggregate material present in concrete inhibits the crack path that occurs where the greater the variation in the addition of silica aggregate material, the shorter the resulting crack path. While in the beam test specimens the resulting crack pattern is a flexural crack, where the flexural crack produced extends along with the increase in the variation of silica aggregate material.

Table 5. Crack pattern of cylinder after 28 days

Variation	No Sampel	Crack type	Average
1	1	Type 2	Type 2
	2	Type 2	
	3	Type 3	
2	1	Type 2	Type 2
	2	Type 2	
	3	Type 2	
3	1	Type 3	Type 2
	2	Type 2	
	3	Type 2	
4	1	Type 2	Type 2
	2	Type 2	
	3	Type 2	
5	1	Type 3	Type 3
	2	Type 2	
	3	Type 3	

Fig. 4. Example of crack pattern of beam specimens

3.5 Design of Rigid Pavement Thickness

In this study, rigid pavement thickness planning was carried out using the 2017 Road Pavement Design Manual (MDP) method, with the following data required:

Table 6. Age Plan

Pavement Type	Pavement Element	Age
Flexible pavement	Asphalt coating and granular coating (2)	20
	Road foundation	
	All pavements for areas where coating is not possible overlay, such as: urban roads, underpasses,	
	Cement Treated Based (CTB)	
Rigid Pavement	Upper foundation layer, subbase layer, cement concrete layer, and road foundations.	40
Uncovered Road	All elements (including road foundation)	Minimum 10

Source: Manual Desain Perkerasan Jalan 2017

Table 7. Traffic growth rate factor (*i*) (%)

	Jawa	Sumatera	Kalimantan	Rata-rata Indonesia
Arteries and cities	4.80	4.83	5.14	4.75
rural collector	3.50	3.50	3.50	3.50
Village Road	1.00	1.00	1.00	1.00

Source: Manual Desain Perkerasan Jalan 2017

1. The road consists of 4 lanes 2 divided directions (4/2D)
2. Type of road based on function, namely Collector roads with Secondary class and IIA.

3.6 Determining the Plan Life

Determination of the plan life for road pavement in MDP 2017[10]. Depends on the type of pavement to be used in accordance with the Pavement Plan Life, the plan life is 40 years (Table 6) with the start of operation in 2024.

3.7 Determine Traffic Growth Factor (I)

Determining the traffic growth factor (i) can be determined based on the rigid pavement table for roads with heavy traffic loads reviewed, namely urban roads located on the island of Sumatra with traffic growth of 4.83% (Table 7).

3.8 Determining Direction and Lane Distribution Factors

The directional distribution factor (DD) is generally used 0.50 except in locations where the number of commercial vehicles tends to be higher in one particular direction. Determination of the value of the lane distribution factor can be determined based on the

Table 8. Lane Distribution Factor (DL)

Number of lanes every direction	Commercial vehicle on design lane (% of commercial vehicle population)
1	100
2	80
3	60
4	50

Table 9. Number of Vehicles Fly Over Design - Anak Aia Intersection

Time	Vehicle Class									
	2	3	4	5a	5b	6a	6b	7a	7b	7c
17.00–17.15	104	1	15	0	0	0	18	9	0	0
17.15–17.30	104	0	13	1	0	4	10	4	0	0
17.30–17.45	132	0	12	0	0	2	10	5	0	0
17.45–18.00	90	1	20	2	0	1	13	7	0	1
Total	430	2	60	3	0	7	51	25	0	1

Table 10. Number of Vehicles Design of Anak Aia Intersection - Fly Over

Time	Vehicle Class									
	2	3	4	5a	5b	6a	6b	7a	7b	7c
17.00–17.15	79	0	6	0	0	2	15	4	0	0
17.15–17.30	77	2	14	0	0	0	5	7	0	0
17.30–17.45	92	1	6	0	0	1	9	4	0	0
17.45–18.00	85	0	5	0	0	1	10	2	0	0
Total	333	3	31	0	0	4	39	17	0	0

Traffic Growth Rate Factor Table (i) On the road under review there are 2 lanes per direction with 80% lane distribution (Table 8).

3.9 Average Daily LHR

Calculation of flexible pavement thickness using vehicle data on Sunday, February 20, 2022 at 17.00–18.00. Motorcycles and light vehicles are not taken into account in the MDP 2017 method planning Table 9 and Table 10.

Table 11. Recapitulation of LHR Calculation of Each Vehicle Type

Transportation type	Vehicle Class	LHR (vehicle/day/2way)
Mobil Kendaraan	2	9583
Oplet, Mini Bus	3	63
Pick-up	4	1011
Bus Kecil	5a	38
Bus Besar	5b	0
Truk 2 Sumbu 4 Roda	6a	138
Truk 2 Sumbu 6 Roda	6b	1189
Truk 3 Sumbu	7a	525
Truk Gandeng	7b	0
Truk Semi Trailer	7c	13
Total		12560

Table 12. Recapitulation of Cumulative Value of Commercial Vehicle Axis Group

Vehicle Types	LHR (2 ways) 2022	LHR 2024	LHR 2027	VDF5 Faktual	VDF5 Normal	ESA5 (‘24-’26)	ESA5 (‘27-’44)
Mobil Penumpang dan kendaraan ringan lainnya	10657	11711	13492	-	-	-	-
5B	38	42	48	1	1	0	0
6A	138	152	175	0,5	0,5	22673	353145
6B	1189	1307	1505	7,4	4,6	2891130	27992612
7A	525	577	665	18,4	7,4	3174177	19883588
7B	0	0	0	-	-	0	0
7C	13	14	16	29,5	9,6	126014	638731
					CESA5	6213993	48868077
					CESA5 2024–2044		55082070

The following is a recapitulation of the calculation of vehicle LHR in units of vehicles/day/direction:

Based on Table 11, it can be seen that the number of vehicles that are widely traveled on the Jalan Anak Aia - fly over intersection is Car Vehicles with a total LHR of 9583 vehicles/day/direction and the total LHR for the 2017 MDP method rigid pavement is 12560 vehicles/day/direction.

3.10 Determining the Volume of the Commercial Axis Vehicle Group

Cumulative load calculation (ESA5) for 20 years (2024–2044) using VDF Table Lane Distribution Factor (DL) and 4.83% traffic growth.

The following is an example of ESA5 calculation for vehicle type 6A:

- Lintas harian rata-rata 2 arah 2022= 138
- Pertumbuhan lalu lintas = 4.83%
- Nilai DD = 0.5
- Nilai DL = 0.8
- VDF Faktual = 0.5 **(Table Faktor Distribusi Lajur (DL))**
- VDF Normal = 0.5 **(Table Faktor Distribusi Lajur (DL))**
- R(24-26) = 2.048
- R(27-44) = 27.69
- LHR 2024 = LHR 2 arah 2021 x $(1 + 0.0483)^3$
  = 138 x $(1 + 0.0483)^3$
  = 152
- LHR 2026 = LHR 2 arah 2021 x $(1 + 0.0483)^5$
  = 138 x $(1 + 0.0483)^5$
  = 175
- ESA5(24-26) = LHR 2024 x VDF5 Faktual x 365 x DD x DL x R
  = 159 x 0.5 x 365 x 0.5 x 0.8 x 2.048
  = 2.26E+04
- ESA5(27-44) = LHR 2026 x VDF5 Normal x 365 x DD x DL x R
  = 175 x 0.5 x 365 x 0.5 x 0.8 x 27.69
  = 3.53E+05

The recapitulation of the cumulative value of the commercial vehicle axis group can be seen in Table 12.

Based on Table 12, the cumulative value of the 2024–2044 commercial vehicle axis group is 55.08E + 06 ESAL.

3.11 Determining the Road Foundation Structure

Based on the calculation of the CBR value with 2 methods, the results obtained with the graphical method are 7.2% and the analytical method is 4.81%, the smallest CBR value used in planning is the analytical method of 4.81%. Based on the Lane Distribution Factor Table, the minimum road foundation design is obtained for CBR 4.81%, then the subgrade strength class is SG.4, which requires subgrade improvement with a minimum repair thickness of 200 mm.

3.12 Define Pavement Layer Structure Table

The cumulative design commercial vehicle axis group is 55.08E + 06 ESAL, based on the Terminal Serviceability Index Table, the flexural pavement thickness is obtained in the following table:

1. Plan life: 20 years (2024 – 2044)
2. Thickness of concrete slab: 275 mm
3. Thin concrete layer (LC): 100 mm
4. Class A Foundation Layer: 150 mm

4 Conclusion

Based on the results of research and planning that has been carried out, the following conclusions are obtained.

1. The highest compressive strength value of concrete is obtained in the 3rd concrete variation with a concrete mixture of 100% Silica sand + Natural gravel + Sikament NN with a value of 41.14 MPa. For the optimum flexural strength value obtained in the 4^{th} concrete mixture (100% natural Sand + Silica Gravel + Sikament NN) with a value of 1.6 MPa. Based on these results in road planning, we use the 4th concrete variation as a variation that will be applied on the basis of its optimum flexural strength value and also with a compressive strength value that exceeds the compressive strength of the plan, namely 32.36 MPa.
2. Planning of rigid pavement on Jalan Simpang Anak Aia - Fly Over Minangkabau International Airport STA 22 + 800 s/d STA 22 + 800 using MDP2017 method obtained pavement thickness of 27.5 cm. So it can be concluded that the results of this research and planning of rigid pavement thickness can be used as an alternative to rigid pavement and also reduce mining waste in the form of silica aggregate material in the environment.

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