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DEVELOPMENT OF FLEXIBLE PAVEMENT STRUCTURE USING THE LOCAL MATERIALS OF SARMI, PAPUA, INDONESIA - BASED ON INDONESIAN NATIONAL SPECIFICATION

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ABSTRACT: Roads are the important thing in development to open regional isolation, including in Sarmi Regency, Papua Province, which is a new expansion area that promotes infrastructure development, especially roads that require material imported from outside the region and will take time and cost. Therefore, using local natural resources is highly recommended. However, it has not been tested in the laboratory. The condition of the road is not good, because it has been paved although has not reached its design life and it has been damaged. Thus, it is necessary to develop a flexible pavement structure using the Indonesian Specification using local materials. A thin layer of Hot Rolled Sheet (HRS) was chosen because Sarmi has a low traffic volume. This research was conducted at the Laboratory the Regional office of public work at Papua Laboratory and the National laboratory Office at Bandung, Laboratory, consisting of 3 parts, namely Surface Course Testing using Crushed Stone and Iron Sand as local materials from Sarmi Papua Quarry (Sample 1), which were then compared to standard materials from Bandung (Sample 2). The results show that Sample 1 had greater stability, was more elastic, more dynamic, and had better resistance carrying loads compared to Sample 2. From the Base Course Testing, the result of compressive strength was within the requirements, 7% (2,343 MPa > 2 MPa), and from the CBR Subgrade Testing, Soaked CBR = 29,5% > 6%. The test results can be recommended as materials that can be used in Sarmi Regency and surrounding areas.

Keywords: Flexible Pavement, Local Materials, Indonesian Specifications, CBR test, Stiffness Modulus

1. INTRODUCTION

Local materials have been used in many places to minimize the cost, travel time, and other risks of transporting materials from outside the region [1–7]. The isolated areas will be difficult to gain materials from outside the area, especially if there is no or few transportations access. Some of road constructions use local materials with additive or modification to strengthen the mixture [8–13]. Nevertheless, the local material that fulfils the minimum requirement of strength is not required to use additives in road construction. Therefore, it is required to test the local material based on standard requirements before it is used in a road [3–5,14–18].

Papua is one of the provinces in Indonesia that has many isolated areas. Access to transportation in Papua is quite hard, resulting in basic commodities being expensive and difficult to reach by the community, making it difficult for them to get welfare [21]. Therefore, it is necessary to build land transportation infrastructure, including roads. Roads are essential for area development to open regional isolation as access for the entry of other developments, such as office buildings, houses, and others.

Sarmi Regency [21,22] is one of the new expansion areas in Papua Province, Indonesia, which is currently promoting infrastructure development in all fields, especially those related to road infrastructure access. The need for roads is very high, thus it requires a lot of materials in the form of rocks, sand, and others. The materials used are from outside the Sarmi area and bringing in materials from outside takes a lot of time and costs, therefore, the use of available natural resources in the form of local materials is highly recommended. However local materials have not been tested in the laboratory regarding their strength, wear, water absorption, and stability when carrying loads.

The general condition of the roads in the Sarmi area is not good, because most of them have been asphalted, but they have undergone damage even though they have not reached the design life. Therefore, this research is necessary to develop a strong flexible pavement structure using local materials in Sarmi Regency, Papua Province, Indonesia, in the form of limestone, crushed stone, and iron sand, following the 2018 Bina Marga General Specifications Revision 2 as a Indonesian National Specification [16].

This research aims to develop the use of local materials, which are abundant in the Sarmi Regency, Papua Province, Indonesia, namely coarse and fine aggregate for the surface course, limestone for the base course [23–25], and subgrade testing in road construction in Sarmi Regency and its surroundings, to save cost and time and thus the distribution of goods and services in all regions can run well and provide welfare for the community.

2. RESEARCH SIGNIFICANCE

The significance of this research is expected to provide input and recommendations to the Local Government regarding the importance of improving road quality by using materials that are available in the location thus it can save budget and shorten the development time. While for material engineers, the results of this research can be used as an innovation about the mixture of road pavement with local materials that are cheap and easy to obtain.

3. RESEARCH METHODS

This research begins with the identification of problems and objective which is how to use local material abundant in a location to optimize cost and time for road construction and do some laboratory test for the material. Consequently, past studies were collected, and Indonesian Standard is reviewed to support and be the guideline for the research. Next, after doing the literature review, the list of data will be considered.

There were two data collection techniques used, namely primary data and secondary data. Primary data is data obtained directly in the field through surveys. The primary data that would be used in this research was the materials from the research location, namely in Sarmi Regency, Papua Province. Secondary Data is data obtained from government and private agencies related to this matter. The secondary data needed was the test results of the flexible pavement surface layer which has been used as a development standard on national roads and Indonesian National Specification [16]. After data were collected, the local material from Sarmi Regency, Indonesia, is tested in a Laboratory including subgrade course, base course, and surface course. The analysis will be conducted based on the result from laboratory test for local material from Sarmi Regency, Indonesia and it will be compared with the national standard in Indonesia. Consequently, the conclusion, suggestion, and recommendation will be written based on the analysis result.

This research was conducted at the Jayapura Papua National Road Implementation Center and the Directorate of Road and Bridge Engineering, Bandung City, West Java, in early 2021.

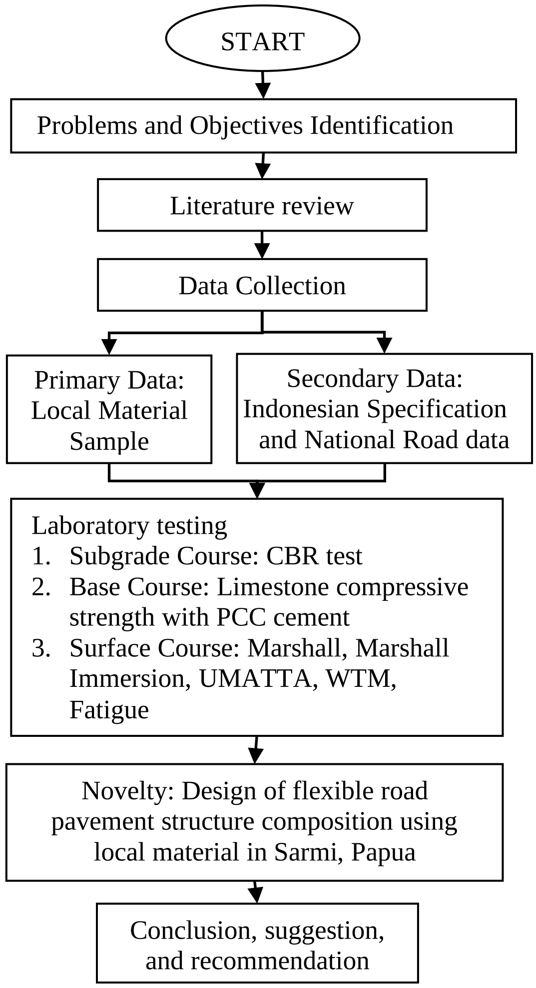


Fig.1 Research methodology

4. DATA ANALYSIS AND RESEARCH RESULTS

The flexible pavement structure research consisted of three parts, which were the Surface Course Testing, Base Course Testing, and Subgrade Testing. For Surface Course Testing, Hot Rolled Sheet (HRS) mixture was chosen because Sarmi Regency has a light average daily traffic (ADT); Crushed Stones and Iron Sand was used as local materials which were taken from Sarmi Regency, Papua Province Quarry as Sample 1, which would be compared with the standard materials from Bandung Regency, West Java Province as Sample2.

Limestone from Sarmi Regency was used as Base Course Testing and Subgrade Testing used the local soil sample also originated from Sarmi Regency in Papua. The structure of flexible pavement is shown in Fig 2. The tests were conducted at the National Laboratory Office in Bandung.

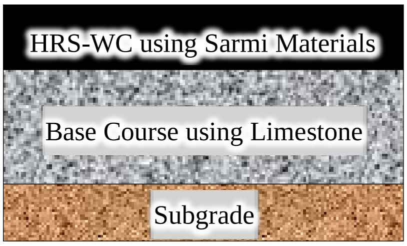


Fig. 2 Flexible Pavement Structure using Sarmi Local Material

4.1 Surface Course Testing

HRS-WC Mixture is produced from aggregate and asphalt binder. The properties of aggregates are shown in Table 1 and Table 2.

Table 1 Properties of Aggregate from Sarmi Regency, Papua Province (Sample 1)

Tests	Aggregate		
	Coarse	Medium	Fine
Los Angeles Abrasion	38%	-	-
Sand Equivalent	-	-	60%
Specific Gravity			
Bulk	2.68	2.63	2.55
SSD	2.72	2.66	2.61
Apparent	2.75	2.72	2.72
Absorption	0.9%	1.2%	2.4%
Angularity	100/100	-	47%
Affinity of Bitumen and Aggregate	-	+95%	-
Sieve Analysis	% Finer		
3/4”	100		
1/2”	14.15	100	
3/8”	3.28	77.18	
# 4	0.23	21.29	
# 8	0.23	1.3	
# 16	0.23	0.04	100
# 30	0.23	0.04	87.76
# 50	0.23	0.04	45.67
# 100	0.23	0.04	20.73
# 200	0.12	0.04	9.88

Source: Laboratory Testing, National Laboratory Office at Bandung, 2021

It can be noticed that the strength of coarse aggregate from Sarmi is lower than standard coarse aggregate from Bandung based on abrasion value. However, based on sand equivalent value, the fine aggregate from Sarmi is cleaner than the standard one. The absorption of coarse aggregate from Sarmi is higher than aggregate from Bandung, but the absorption of fine aggregate is the opposite. All properties of aggregates meet the requirements that it can be used in asphalt mixtures. The asphalt binder used in this testing is pen 60/70 asphalt, the properties are shown in Table 3.

Table 2 Properties of Aggregate from Bandung, West Java Province (Sample 2)

Tests	Aggregate		
	Coarse	Medium	Fine
Los Angeles Abrasion	17.5%	-	-
Sand Equivalent	-	-	53%
Specific Gravity			
Bulk	2.608	2.671	2.588
SSD	2.66	2.71	2.62
Apparent	2.76	2.78	2.69
Absorption	2.1%	1.5%	1.4%
Angularity	100/100	-	47%
Affinity of Bitumen and Aggregate		+95%	-
Sieve Analysis	% Finer		
1”	100		
3/4”	96	100	
1/2”	40.7	98.8	
3/8”	23.1	79.4	100
# 4	7.2	19.2	98.4
# 8	3.9	6.5	80.2
# 16	3	4.4	57.6
# 30	2.6	3.6	41.3
# 50	2.3	3.1	28.8
# 100	1.9	2.5	20.2
# 200	1.4	1.9	14.3

Source: Laboratory Testing, National Laboratory Office at Bandung, 2021

Table 3 Properties of Pen 60/70 Asphalt

Tests	Result
Penetration at 25°C, 100-gram, 5 sec	61 dmm
Kinematic Viscosity at 135°C	319.9 cSt
Softening Point	48.3°C
Ductility at 25°C, 5 cm/min	> 140 cm
Flash Point (COC)	346°C
Solubility in Trichloroethylene	99.9°C
Specific Gravity	1.039
Paraffin Wax Content	0.27°C
Residue Test after Thin Film Oven Test (TFOT) at 163°C, 5 hours	
Loss on Heating	0.01%
Penetration at 25°C, 100-gram, 5 sec	75%
Ductility at 25°C, 5 cm/min	> 140 cm

Source: Laboratory Testing, National Laboratory Office at Bandung, 2021

The asphalt mixture test consisted of 4 types, namely: HRS-WC Mixture Characteristic Testing using the Marshall Test Tools, Resilient Modulus Test, Wheel Tracking Test, and Fatigue Test. The following results from Marshall Test Tools were obtained: Optimum Asphalt Content (OAC) = 6,375% (Sample 1) and 6,8% (Sample 2), Stability = 1700 (Sample 1) and 1043 (Sample 2); Flow = 3,46 (Sample 1) and 3,63 (Sample 2); and Residual Stability (Marshall Immersion) = 91,3% (Sample 1) and 92,9 (Sample 2), where both samples fit the specifications.

Table 4 HRS-WC Mixture Characteristic Testing Results

Testing Type	Testing Results	
	Sample 1	Sample 2
OAC (%)	6.275	6.8
Density (ton/m3)	2.265	2.325
VMA (%)	18	18.5
VIM (%)	5	3.77
VFA (%)	73	79.39
Stability (kg)	1700	1043
Flow (mm)	3.5	3.63
Residual Stability (%)	91.3	92.9
Filler-Asphalt Ratio	2	1.41

Source: Laboratory Testing, National Laboratory Office at Bandung, 2021

Based on Table 1, HRS-WC from Sample 1 had greater stability in bearing loads compared to Sample 2. Its high level of stability, that is more than 1000 indicates high strength mixture, as good as Asphaltic Concrete (AC). The asphalt content higher than 6% is a common characteristic of HRS mixtures. The residual stability shows the mixture durability to extreme weather, such as storm and heat. Compared to standard materials in Bandung, Sarmi materials, especially the iron sand used, provide better strength and less asphalt binder required.

Resilient Modulus Testing using UMATTA Test Tool. The Resilient Modulus is the elastic modulus based on the recoverable strain with repetitive loading. Resilient Modulus is the most important parameter in the mechanical analysis of pavement. The resilient modulus testing was conducted with five pulse pulse repetitions with a repetition period of 3000 ms and loading pulse width of 250 ms. This research was done at 2 temperatures, namely at 25ºC and 35ºC. The results show HRS-WC at a temperature of 25ºC has Resilient Modulus for Sample 1 about 2367.5 MPa and for Sample 2 about 2229 MPa. Additionally, Resilient Modulus of HRS-WC at a temperature of 35ºC for Sample 1 was 933 MPa and for Sample 2 was 571 MPa. The result indicates that HRS-WC mixture using Sarmi materials has higher stiffness compared to the other one using standard materials. High modulus can be beneficial related to layer thickness required for the pavement structure. It also helps to protect base and subgrade from high level stress in soft soil areas.

Table 4 Results of HRS-WC Resilient Modulus Testing at a temperature of 25°C

Details	Sample 1 Average 2 tests	Sample 2 Average 2 tests
Resilient Modulus (MPa)	2367.5	2229
Total Recoverable horizontal deformation	8.74	9.405
Peak Loading Force (N)	1997	1992.5
Recoverable Horizontal Deformation-1 (µm)	4.77	3.88
Recoverable Horizontal Deformation-2 (µm)	3.97	5.53
Seating Force (N)	203.5	198.5

Source: Laboratory Testing, National Laboratory Office at Bandung, 2021

Table 5 Results of HRS-WC Resilient Modulus Testing at a temperature of 35°C

Details	Sample 1 Average from 2 tests	Sample 2 Average from 2 test
Resilient Modulus (MPa)	944	571
Total Recoverable horizontal deformation (µm)	17.01	26.93
Peak Loading Force (N)	1513	1487
Recoverable Horizontal Deformation-1 (µm)	9.56	13.53
Recoverable Horizontal Deformation-2 (µm)	7.45	13.41
Seating Force (N)	146.5	152.5

Source: Laboratory Testing, National Laboratory Office at Bandung, 2021

Based on result laboratory test, it shows that Sample 1 was more elastic when subjected to deformation that occurred at each repetitive load and it could completely return and was proportional to loading compared to Sample 2. At a temperature of 25°C, the difference of resilient modulus is not significant. However, at temperature of 35°C, the resilient modulus of Sample 1 is significantly higher (almost twice) than Sample 2. This means the mixture using Sarmi materials has lower susceptibility to temperature. Hence it has potential to be used in surrounding areas in Papua that are warmer than Sarmi.

To determine the resistance of the HRS-WC asphalt mixture based on Sample 1 and Sample 2 to permanent deformation, a dynamic stability test was conducted. The tests used Wheel Tracking Machine and were conducted at 60°C. The test results were then reviewed on two parameters. The two parameters were: dynamic stability and rate of deformation.

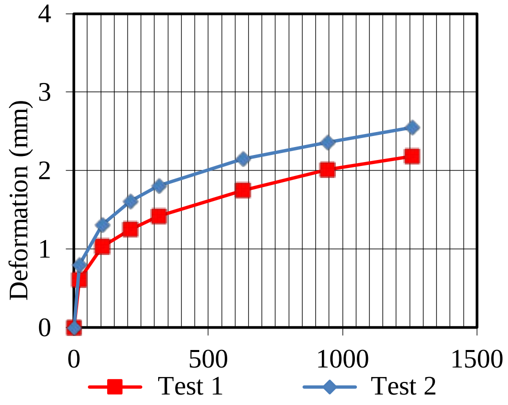


Fig.3 Graph for results of dynamic stability testing at 60ºC for Sample 1
Source: Laboratory Testing, National Laboratory Office at Bandung, 2021

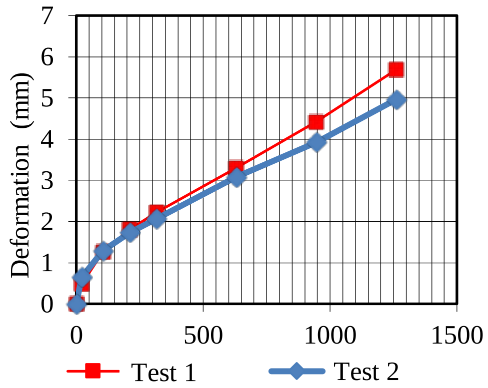


Fig.4 Graph for Results of Dynamic Stability Testing at 60ºC for Sample 2
Source: Laboratory Testing, National Laboratory Office at Bandung, 2021

Sample 1 had dynamic stability of 3510.85 tracks/mm, greater than Sample 2 mixture which had a dynamic stability of 550.95 tracks/mm. The average deformation rate of Sample 1 is 0.012 mm/minute while the deformation rate of Sample 2 is 0.077 mm/minute. These results mean mixture using Sarmi materials has better resistance to permanent deformation than the one using standard materials from Bandung.

HRS-WC Resistance to Fatigue Testing used the Beam Fatigue Apparatus (BFA) Tool. The results of Sample 1 HRS-WC Fatigue Testing show that Sample 1 had a slightly better resistance to fatigue cracking due to repetitive load compared to Sample 2. The final equations are:

$$\boldsymbol{Sample\ 1: \ \varepsilon = 7210,1\, Nf^{-0,275}} \quad (1)$$

$$Sample\ 2: \ \varepsilon = 6149,4\, Nf^{-0,238} \quad (2)$$

Table 6 Results of HRS-WC Fatigue Tests

No	Tensile Strain	Cycles to Failure	
		Sample 1	Sample 2
1	600 µs	21420	19030
2	500 µs	28530	33960
3	400 µs	100410	79960

Source: Laboratory Testing, National Laboratory Office at Bandung, 2021

Fig 5 illustrates that asphalt mixture using Sarmi materials has longer fatigue life than the one using standard materials. On the other hand, the equations show that sample 1 has a higher polynomial coefficient than sample 2, indicating that the mixture using Sarmi materials is more sensitive to traffic loading than the other. Therefore, it is best to be used to low traffic loading. All test results of HRS-WC suggest that the use of Sarmi local materials is better than standard materials from Bandung due to its higher stability, resilient modulus, resistance to permanent deformation, and fatigue life.

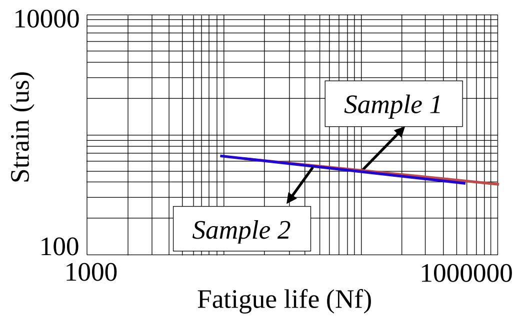


Fig.5 Graph of the Results of HRS-WC Resistance to Fatigue Testing
Source: Laboratory Testing, National Laboratory Office at Bandung, 2021

4.2 Base Course Testing

Examination of limestone characteristics was conducted to determine the feasibility of limestone to be used in the research, considering that limestone is the main material of the base course. These tests were conducted using limestone material from Sarmi Regency, Papua Province.

Table 7 Limestone Properties

No.	Physical Characteristics	Examination Result
1	Specific Gravity	2.619
2	Sieve Analysis	< 35% passed no. 200
3	Atterberg Limits	
	a. Liquid Limit (LL)	19.10%
	b. Plastic Limit (PL)	16.19%
	c. Plasticity Index (PI)	2.91%
4	Soil Classification	A-1-b
5	Mechanical Characteristics	
	Compaction	
	a. γ_{dry}	1.78gr/cm^3
	b. W_{opt}	14.60%
6	Compressive Strength	0.44 MPa

The results of the sieve analysis test show that the limestone that passed sieve no. 200 (0.075 mm) was less than 35%, (22.65%). Liquid Limit (LL) = 19.10%, Plasticity Index (PI) = 2.91% < 6%, therefore the limestone could be classified into group A-1-b, the Stone Fragment classification. With compressive strength about 0.44 MPa, limestone material cannot be used alone as base course material. The solution is to combine this limestone with Portland Cement (PC) to increase its strength. The cement treated base using limestone reported in studies was able to bear traffic loads in pavement structure [26,27].

The PC used water content of 11.5%. From the test results, a maximum compressive strength for 28 days of 410 kg/cm^2 was obtained, greater than the SNI standard, which is 250 kg/cm^2. Therefore, the PC met the specifications for building materials and could be used as a limestone stabilizer material.

The modification of limestone bonded and mixed with composite PC paste supports mineralogy alteration, which results in compressive strength. The mixture of Limestone with cement variations of 3%, 5%, and 7% showed maximum compressive strength with values of 1.363 MPa, 1.703 MPa, and 2.343 MPa, respectively as shown in Fig.7. It is noticed that the compressive strength of Limestone is increased with addition of PCC. The value of the required free compressive strength for the Soil-Cement Composite Base Course according to Indonesian Specification is a minimum of 2 MPa and a maximum of 3.5 MPa. The mixture of limestone with a cement variation of 7% met the specifications for Base Course materials.

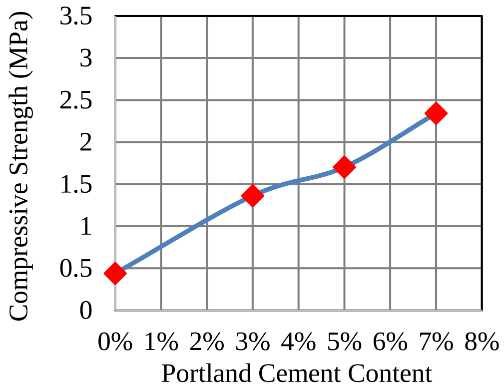


Fig.7 Improvement of Limestone Compressive Strength with addition of PC

4.3 Subgrade Testing

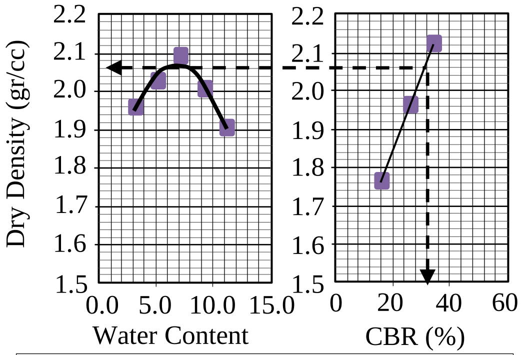
In the subgrade research, soil samples were taken in Sarmi Regency, Papua Province. Three tests were conducted: subgrade properties testing, compaction experiment, and CBR testing. Table 8 shows subgrade properties testing results.

Table 8 Subgrade Properties

No.	Tests	Results
Physical Properties		
1	Specific Gravity	2,566
2	Sieve Analysis	< 35% lolos no.200
3	Atterberg Limits	
	a. Liquid Limit (LL)	16,20%
	b. Plastic Limit (PL)	10,60%
	c. Plasticity Index (PI)	5,60%
4	Soil Classification	A – 2 - 4
Mechanical Properties		
1	γ_d max	2,060 gr/cm^3
2	Optimum Moisture Content (OMC)	7,00%
3	CBR (Soaked)	29,5%
4	Plasiticity Index	5,60
5	Liquid Limit	16,20

The results of the sieve analysis test show that the limestone that passed sieve no. 200 (0.075 mm) was less than 35%, (30.92%) with a Liquid Limit (LL) of 16.20%, which was less than a maximum of 40%, then the subgrade could be classified into group A-2-4, Gravels and Silty Sand or Loamy Sand Classification. From the results of the compaction experiment, OMC of 7% and maximum γ_d of 2.060 gr/cc were obtained.

The CBR test was made in 3 types of collisions, namely CBR10, CBR35, and CBR65, which were then inserted into the graph. Then, a soaked CBR value of 29.5% was obtained, with a minimum limit of 6%. The strength of subgrade is significantly higher than the minimum limit indicates good soil strength. The subgrade could be used and met the requirements for subgrade strength.



γ_d Max	=	2.060	(gr/cc)
CBR	=	29.5	(%)
OMC	=	7.00	(%)

Fig.7 Density Value and CBR Analysis of Subgrade

5. CONCLUSION

The flexible road pavement development refers to the method from Indonesian Specification using local materials. In this research, a thin layer of Hot Rolled Sheet (HRS) was chosen because the Sarmi regency has a considered low traffic volume.

This research consisted of 3 parts, namely the Surface Course Testing (Marshall, Marshall Immersion Test, Fatigue Test, UMATTA Test, and Wheel Tracking Test) using local materials, namely Crushed Stone and Iron Sand from Sarmi Papua Quarry (Sample 1), which were then compared to standard materials from Bandung (Sample 2). The results show that Sample 1 had greater stability, was more elastic, more dynamic, and had better resistance to carrying loads compared to Sample 2. From the Base Course Testing, the result of compressive strength was within the requirements, 7% (2.343 MPa > 2 MPa), and from the CBR Subgrade Testing, Soaked CBR = 29.5% > 6%.

The Sarmi Regency may use local materials because the results met the requirements, even higher than the standard materials.

6. RECOMMENDATIONS

The Sarmi Regency Government is expected to use existing local materials because the results of this research show that the local materials used, namely crushed stone, limestone, and iron sand are included in the requirements of the Indonesian Specification and the results are so much better and stronger than the Indonesian standard aggregates.

The use of local materials must go through testing in the laboratory to get maximum results according to the design life and to last a long time.

7. ACKNOWLEDGMENTS

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