

CHAPTER IV

RESULT AND DISCUSSION

4.11. Introduction

The aim of this study is to find out the way to achieve the viability of using crumb rubber as the additive material in the hot asphalt concrete modified with a certain comparison is expected to improve the quality of the asphalt and to know the properties of asphalt added with crumb rubber.

In the comparison between the two types (without and with crumb rubber) of properties of the hot mix split mastic asphalt toward the Marshall properties (stability, flow, MQ, VITM, VFWA, and air void to get maximum asphalt contact, ISTM, and UCS at different test temperature 30°C ITS at different test temperature of 30°C, 40°C, and 60°C and permeability test.

The methodology used for this study has been discussed in chapter 3. The results of each procedure in determining the properties are presented in this chapter and will be further analyzed and discussed in depth.

4.12. Materials and Properties

The main materials used for this study were: asphalt AC 60/70 coarse aggregate (crushed stones), fine aggregate, and CR.

All main properties of the materials used were measured for further analysis consideration. Several tests were conducted in order to measure their properties according to the specifications referred. The reference used are AASHTO and Bina Marga standard.

4.12.1. Asphalt

The properties test of asphalt AC 60/70 produced by PT. PERTAMINA was used. Table presents the results of properties test asphalt AC 60/70, Table 4.1 shows some properties of the bitumen 60/70. This test was conducted according to (Bina Marga, 2010) presents the results of properties test for each type of asphalt 60/70.

Table 4.1. Result of properties test of asphalt AC 60/70

No	Characteristics	Result	Specification (Bina Marga)
1	Specific gravity of asphalt	1.045	Min .1
2	Penetration (mm)	63.5	60-79
3	Ductility (cm)	164	Min. 100
4	Flash point and fire point ©	320 -326	Min. 200
5	Softening point (c)	48.35	48 - 58
6	Asphalt solubility in TCE (tri chlore enthelyn)/CCL	99.59	MIN .99

4.12.2. Aggregate

The aggregate used as the materials for the split mastic asphalt mix. Based on the properties test of coarse aggregate and fine aggregate result as table

A. Properties of Aggregates

At the preliminary stage, aggregate were sieved according to Indonesian standards and separated according to the size of sieves on the selected aggregate gradation. The total weight of aggregates needed was 1200 grams. The aggregate gradation specification for AC and the selected gradation used in this study are shown in Table 2.2 and Figure 4.1

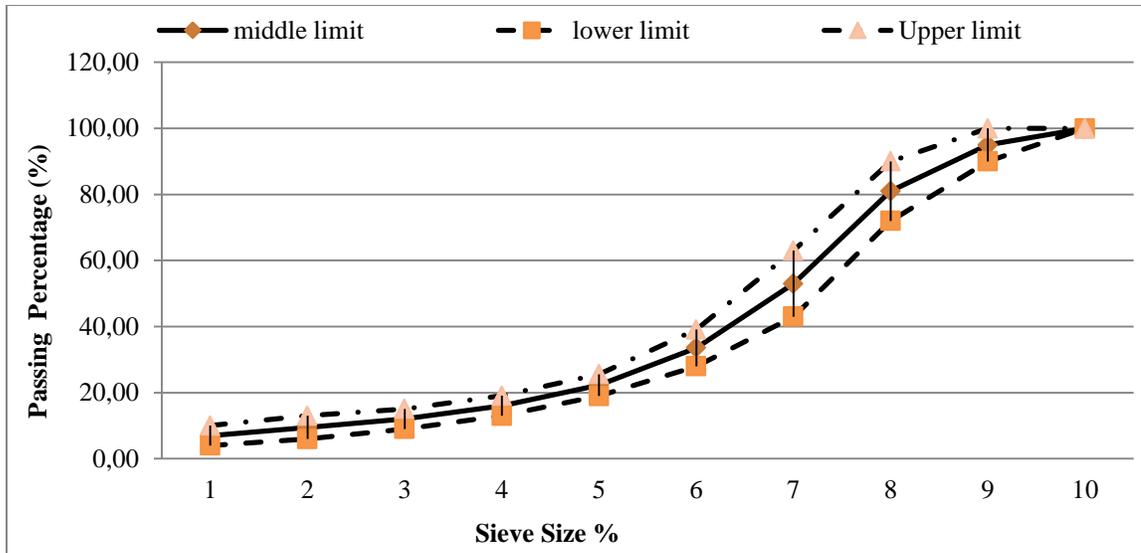


Figure 4.1 Gradation limit for asphalt concrete

Based on Figure 4.1, it can be concluded that the selected aggregate gradation used in this study can fulfil the gradation requirement specified by Bina Marga (2006). Similar with asphalt concrete, the aggregate materials are required to be tested to evaluate whether their properties fulfil the requirements or not. Several aggregate properties were measured in this study, such as specific gravity, abrasion, flakiness and elongation indices, and so on, to make sure that the aggregates used could be used in making the asphalt mixtures. The results of the aggregate tests are presented in the Tables 4.2 & Table 4.3.

Table 4.2. Properties of coarse aggregate

No	Properties	Result	Specification (Bina Marga)
1	Bulk specific gravity of coarse aggregate	2.64	≥ 2.5
2	SSD specific gravity of coarse aggregate	2.67	≥ 2.5
3	Apparent specific gravity of coarse aggregate	2.714	≥ 2.5
4	Water absorption of coarse aggregate	1.02	≤ 3
5	Abrasion	21.31	≤ 40
6	Adhesiveness	99	≥ 95

Table 4.3. Properties of fine aggregate

No	Properties	Result Fine aggregate	Specification (Bina Marga)
1	Bulk specific gravity of fine aggregate	2.52	≥ 2.5
2	SSD specific gravity of fine aggregate	2.59	≥ 2.5
3	Apparent specific gravity of fine aggregate	2.723	≥ 2.5
4	Water absorption of fine aggregate	2.94	≤ 3

4.13. Marshall Test of 60/70 Bitumen Mixture

Two types of Marshall Test are the materials for the asphalt concrete without crumb rubber, and asphalt concrete modified with crumb rubber. Marshall Test for the 60/70 (asphalt without crumb rubber) within the range 2.5%, 5.0%, 7.5% and 10% are used. The OBC in asphalt concrete without CR has been determined in this study based on the maximum stability according to the MS. Table 4.4 shows some properties of the 60/70 (asphalt without crumb rubber).

Table 4.4. Properties of asphalt concrete without crumb rubber (60/70)

No	Bitumen Content (%)	Stabilities Kg	Flow (mm)	VFWA	Air void	MQ	Density	VMA
1	5.0	1035.33	2.80	61.44	6.91	369.85	2.29	17.92
2	5.5	1336.90	3.22	66.89	6.14	415.72	2.29	18.26
3	6.0	1412.80	3.40	70.31	5.59	415.02	2.29	18.79
4	6.5	1328.01	3.17	75.92	4.65	418.29	2.30	19.00
5	7.0	1166.02	2.67	80.60	3.73	441.71	2.30	19.22

This relationship between the stability and the asphalt content is shown in Figure 4.2

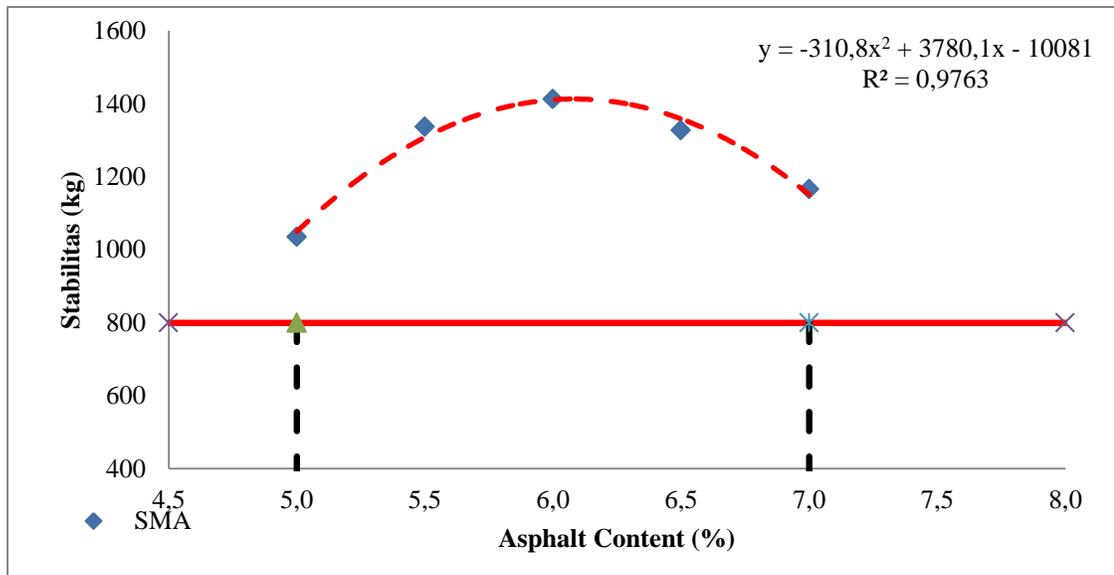


Figure 4.2. Correlation stability and AC without CR toward asphalt content

Through the review of the stability test results in Table 4.4 and Figure 4.2 the following observations were obtained that the highest stability value of asphalt concrete without crumb rubber is asphalt content 6.0% by 1412.80 kg and the smallest stability is asphalt content 5.0% by 1035.33 and 7.0% by 1166.02 kg. Thus it can be concluded that the higher percent and smaller percent of the asphalt content decreases stability. Thus addition of asphalt content will give the higher penetration or softer. As a result, the mixture becomes more flaccid so as to contribute to the decrease in the value of stability.

This relationship between the flows and the asphalt content is shown in Figure 4.3

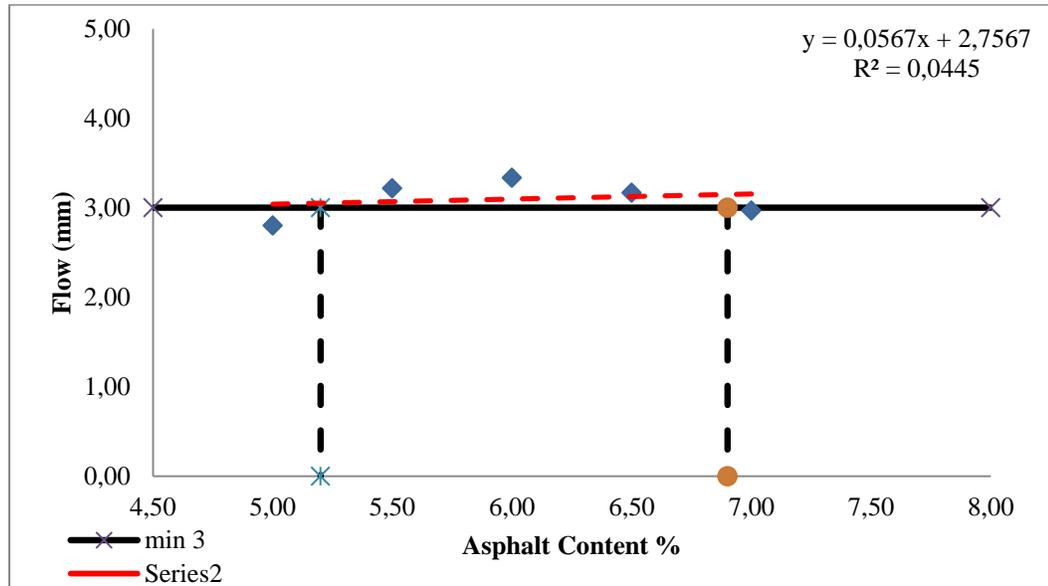


Figure 4.3. Correlation flows and AC without CR toward asphalt content

Through the review of the flow test results in Table 4.4 and Figure 4.3 the following observations were obtained that flow value of asphalt concrete without crumb rubber is 6% by 3.40 mm and smallest with asphalt content 5.0% by 2.8 mm, 5.5% by 3.22 mm, 6.5% by 3.17 mm, and 7% by 2.67 mm. Thus it can be concluded that the higher the asphalt content the more the flow will be. With the addition of the asphalt content will affect the mixes become more flexible and the resistance to deformation decreases resulting in a high flow value. But this value is considered very low compared to global standards as well as specifications Indonesian.

This relationship between the Marshall quotients and asphalt content is shown in Figure 4.4.

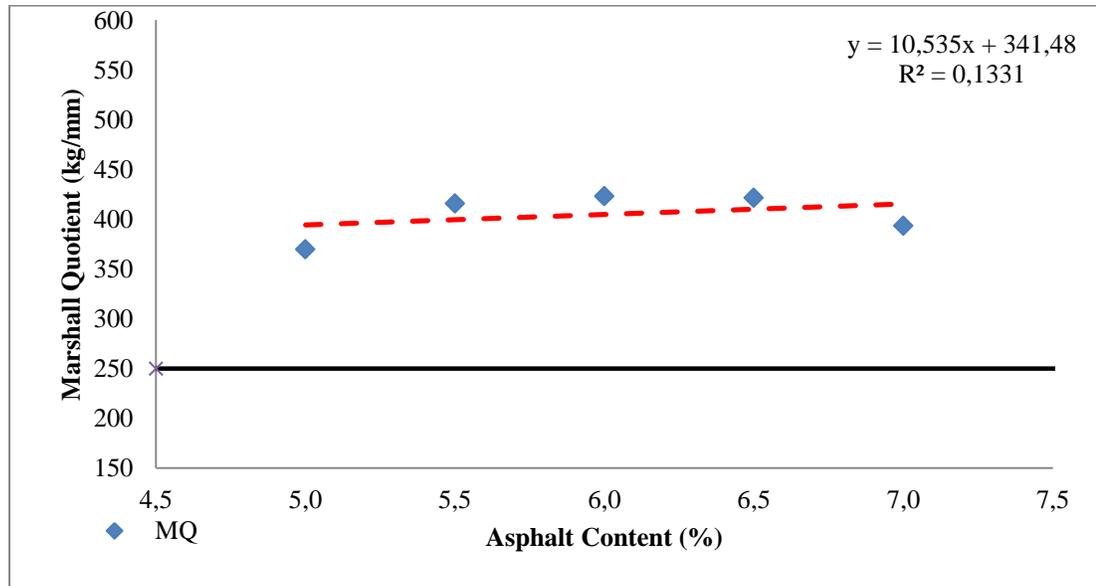


Figure 4.4. Correlation MQ and AC without CR toward asphalt content

Through the review of the marshal quotient test result in Table 4.4 and Figure 4.4 were obtained the following observations that the marshal quotient value of asphalt concrete without crumb rubber is highest with asphalt content 6.0% by 423.06 kg/mm and is smallest with asphalt content 5% by 369.85 kg/mm. Thus it can be concluded that the higher the asphalt content decreases marshal quotient.

Marshall Quotient also known as rigidity ratio, which is the ratio of stability to flow value of the mixture and the Marshall Quotient values of AC. So the increase in the flow value will decrease the Marshall Quotient value.

This relationship between the air void and the asphalt content is shown in Figure 4.5

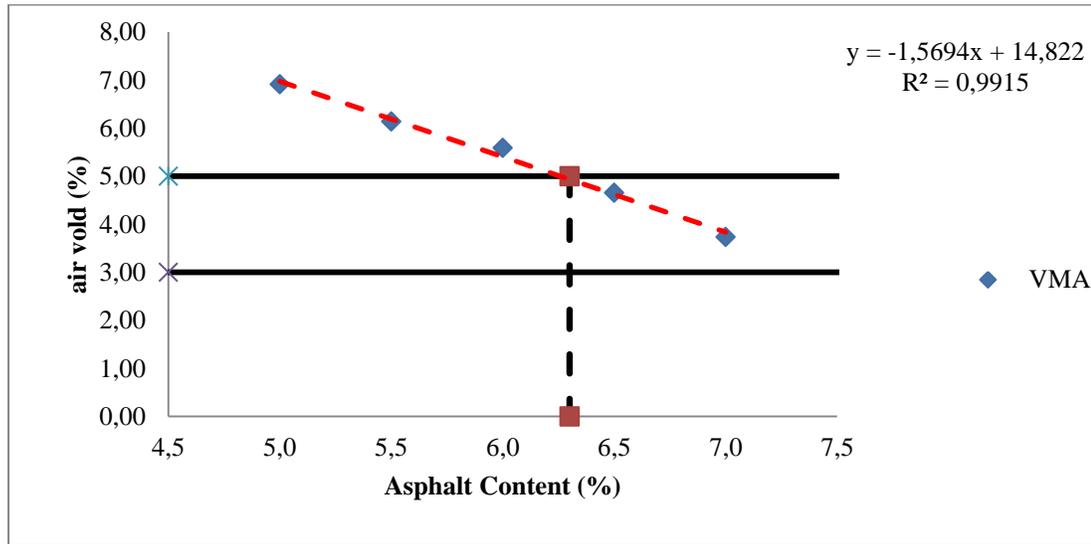


Figure 4.5. Correlation air void and AC without CR toward asphalt content

Through the review of the air void test results in Table 4.4 and Figure 4.5 the following observations were obtained that the air void value of asphalt concrete without crumb rubber is highest with asphalt content 5.0% by 6.91 and smallest with asphalt content 7.0% by 3.73. Thus it can be concluded that the higher the asphalt content decreases air void.

Excessive air voids in the mixture would result in cracking due to insufficient bitumen binders to coat on the aggregates, while too low air void may induce more plastic flow (rutting) and bitumen bleeding.

This relationship between the VFWA and the asphalt content is shown in Figure 4.6

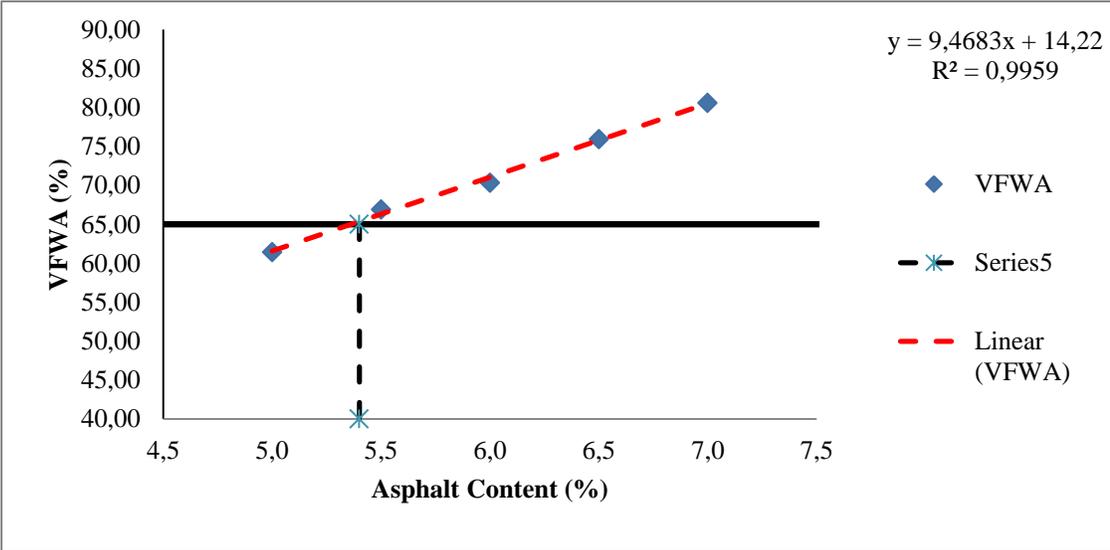


Figure 4.6. Correlation VFWA and AC without CR toward asphalt content

Through the review of the VFWA test results in Table 4.4 and Figure 4.6 were obtained the following observations that the VFWA value of asphalt concrete without crumb rubber is highest with asphalt content 7.0% by 80.60% and is smaller with asphalt content 5.0% by 61.44%. Thus it can be concluded that the higher the asphalt content increases void filled with asphalt. This is due to the addition of asphalt content, and then the value of void filled with asphalt increases.

This relationship between the VMA and the asphalt content is shown in Figure 4.7

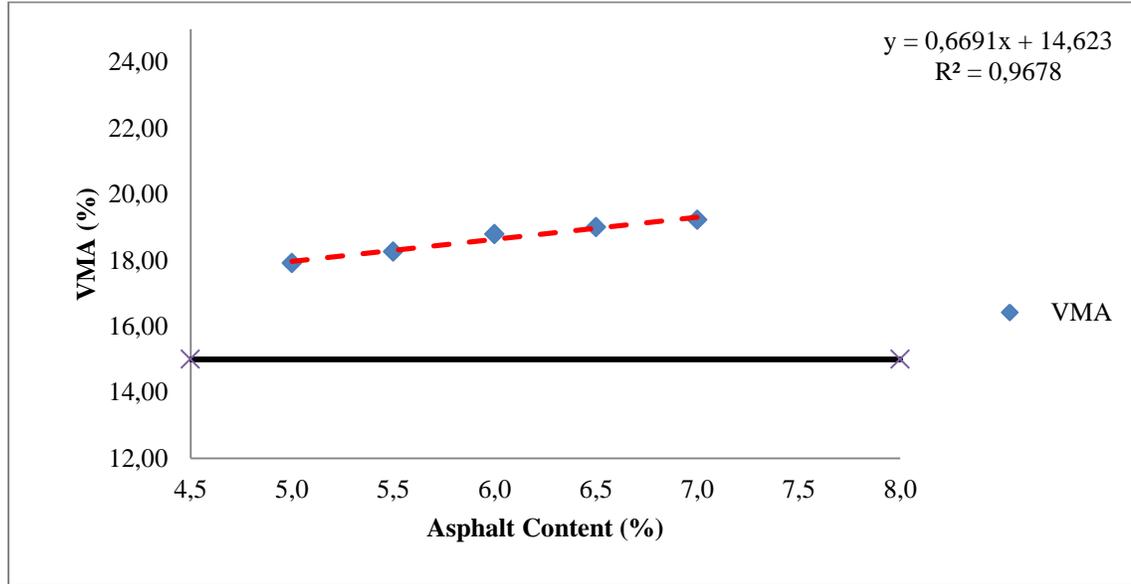


Figure 4.7. Correlation VMA and AC without CR toward asphalt content

Through the review of the VMA test results in Table 4.4. and Figure 4.7. the following observations were obtained that the VMA value of asphalt concrete without crumb rubber is highest with asphalt content 7.0% by 19.22% and is smaller with asphalt content 5.0% by 17.92%. Thus it can be concluded that the higher the asphalt content increases Void in total mix. With the addition of asphalt content will decrease the volume of intergranular void space between the aggregate particles of a compacted paving mixture. It included the air voids and the volume of bitumen not absorbed into the aggregate.

Thus it concluded When VMA is too low, there is not enough room is the mixture to add sufficient bitumen binder to coat adequately over the individual aggregate particles. Also mixes with a low VMA are more sensitive to small changes in bitumen binder content. Excessive VMA will cause unacceptably low mixture stability.

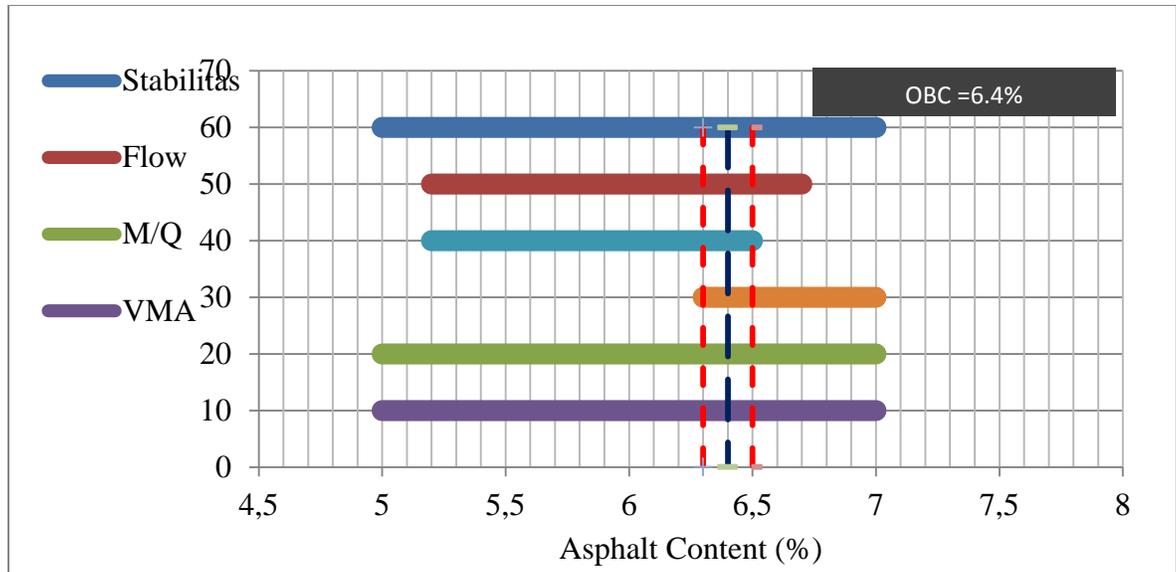


Figure 4.8. Correlation Marshall Properties toward % bitumen

Through the review of the Marshall Properties test results in Table 4.4. the following observations were obtained that the OBC in the asphalt concrete without crumb rubber is 6.4% bitumen, that is shows in figure 4.8

4.14. The Influence of CR Additive on The Properties of AC.

Marshall Test was done for the asphalt concrete with crumb rubber within the range given 2.5%, 5.0%, 7.5%, and 10%. The OBC has been determined in the study based on the maximum stability according to the MS.

4.14.1. Properties of Asphalt Concrete With 2.5% Crumb Rubber.

Table 4.5. shows some properties of asphalt concrete modified with crumb rubber 2.5%.

Table 4.5: Properties of asphalt concrete with 2.5% crumb rubber (60/70)

Asphalt Content (%)	Stabilities Kg	Flow mm	VFWA	Air voids	MQ	Density	VMA
5.0	896.78	3.00	59.96	7.37	299.28	2.28	18.33
5.5	1056.50	3.53	67.97	5.77	300.22	2.30	17.94
6.0	1181.26	3.80	71.41	5.32	311.34	2.30	18.57
6.5	1172.59	3.47	74.99	4.79	339.50	2.29	19.12
7.0	1029.50	2.80	82.82	3.23	367.41	2.31	18.81

This relationship between the stability and the asphalt content with CR 2.5% is shown in Figure 4.9.

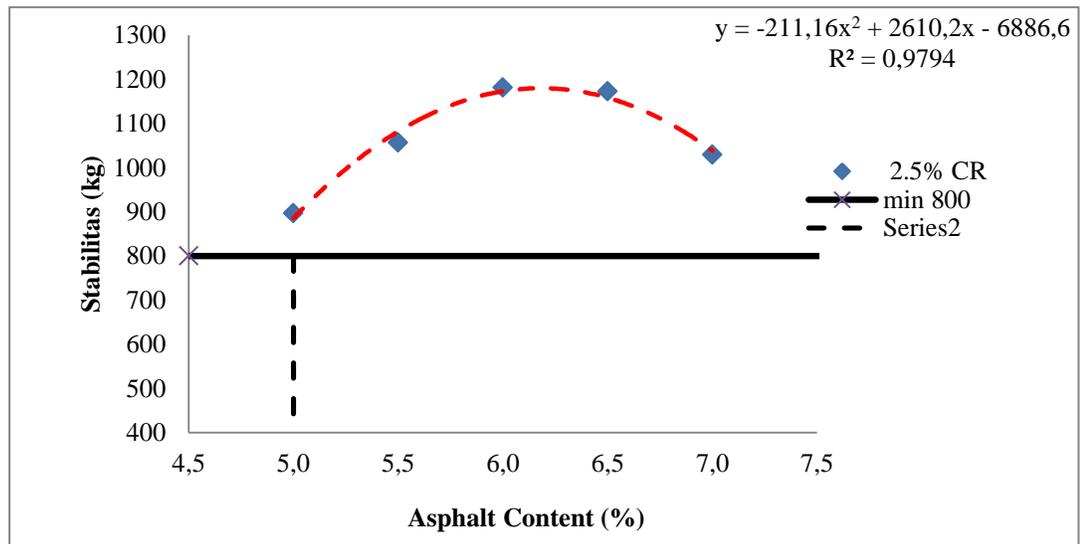


Figure 4.9. Correlation stability and AC with 2.5% CR toward asphalt content

Through the review of the stability test results in Table 4.5 and Figure 4.9 the following observations were obtained that the stability value of asphalt concrete with crumb rubber is highest with asphalt content 6.5% by 1181.26 kg and is smallest with asphalt content 5.0% by 896.78 with add the 2.5% crumb rubber effect at the cohesion and the bonding stability of modified bitumen decrease. So the stability value of asphalt

concrete modified without crumb rubber is higher than asphalt concert with crumb rubber, but the stability increases along with the increase of CR content up to a certain extent (optimum) and decreases after it passes the optimum limit. This happens because the asphalt as the binding material between the aggregate can become a lubricant after the optimum limit as the binding.

This relationship between the flows and the asphalt content is shown in Figure 4.10

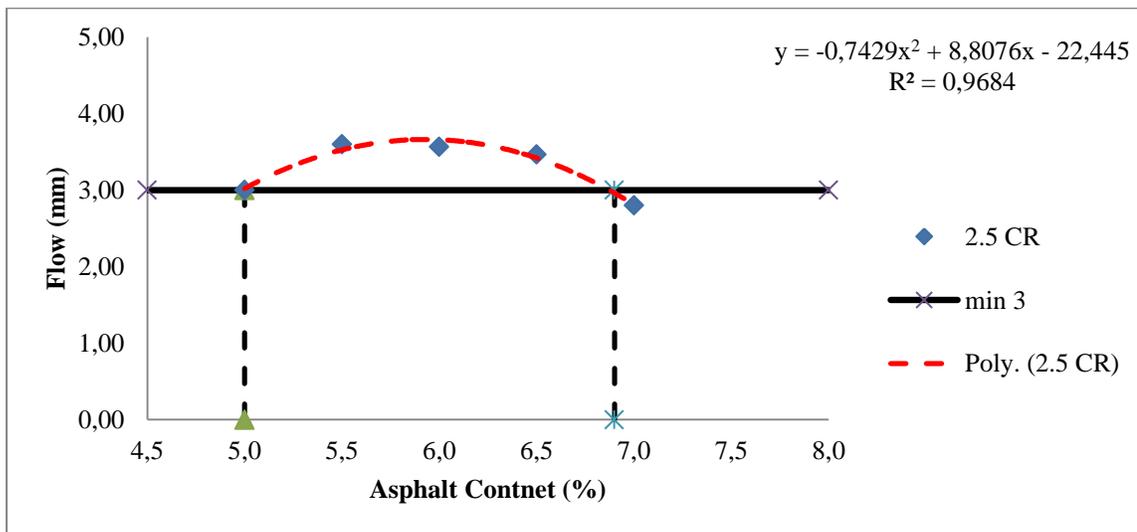


Figure 4.10. Correlation flows and AC with 2.5% CR toward asphalt content

Through the review of the flow test results in Table 4.5. and Figure 4.10 were obtained the following observations that flow value of asphalt concrete with crumb rubber 2.5% is highest with asphalt content 6.0% by 3.80 mm and smallest with asphalt content 7.0% by 2.8 mm. Thus it can be concluded that the higher the asphalt content increases flow. With the addition of the asphalt content will affect the mixes become less flexible and the resistance to deformation decreases resulting in a high flow value.

This relationship between the Marshall quotients and the asphalt content with CR 2.5% is shown in Figure 4.11.

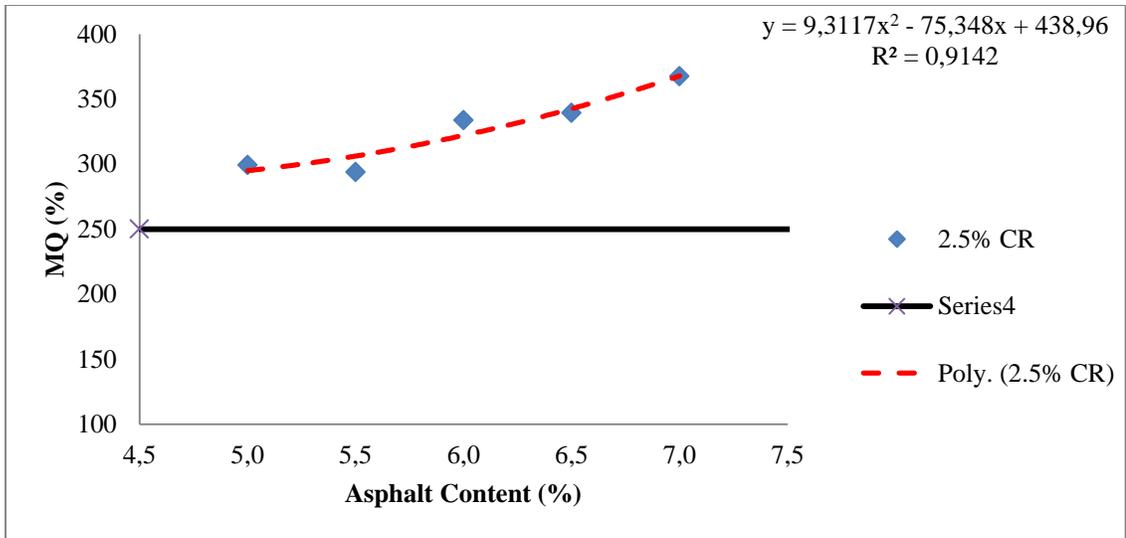


Figure 4.11. Correlation MQ and AC with 2.5% CR toward asphalt content

Through the review of the Marshall quotient test results in Table 4.5. and Figure 4.11. the following observations were obtained that Marshall quotient value of asphalt concrete with crumb rubber 2.5% is highest with the 7.0% by 367.41 mm and smallest with asphalt content 5.0% by 299.28 mm. Thus it can be concluded that the 2.5% CR with % bitumen increases Marshall Quotient.

This Figure 4.12 relationship between the air void and the asphalt content with CR 2.5% is shown in

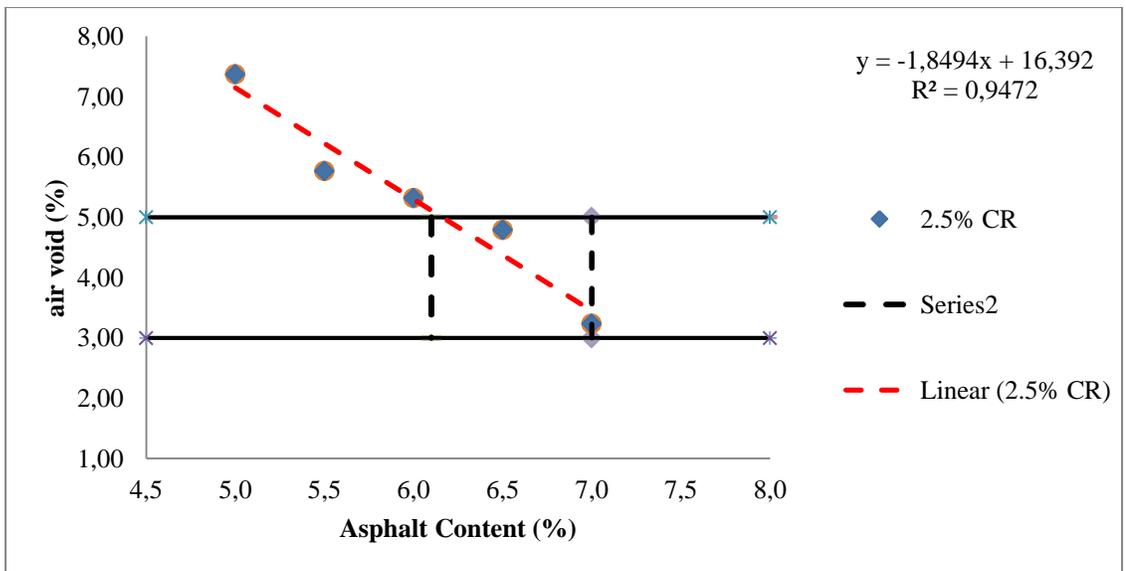


Figure 4.12. Correlation air void and AC with 2.5% CR toward asphalt content

Through the review of the air void test results in Table 4.5. and Figure 4.12. the following observations were obtained that air void value of asphalt concrete with crumb rubber 2.5% is highest with the 5.0% by 7.37% and smallest with asphalt content 7.0% by 3.23%, 6.5% by 4.79%, 6.0% by 5.32%, and 5.5% by 5.77%. Thus it can be concluded that the 2.5% CR with % bitumen decreases air void.

This relationship between the VMA and the asphalt content with CR 2.5% is shown in Figure 4.13

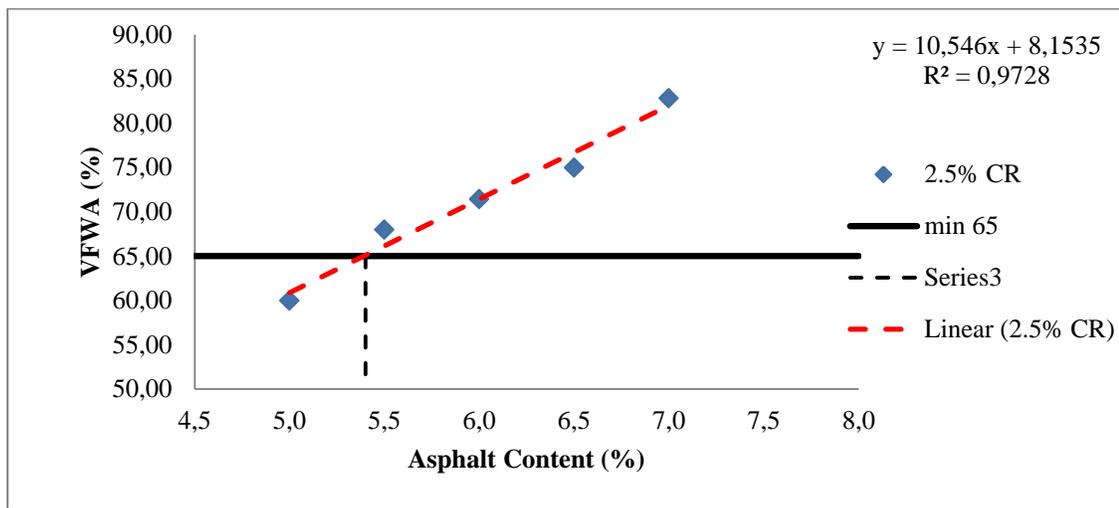


Figure 4.13. Correlation VFWA and AC with 2.5% CR toward asphalt content

Through the review of the VITM test results in Table 4.4 and Figure 4.13 the following observations were obtained that VITM value of asphalt concrete with crumb rubber 2.5% CR is highest with the 7.0% by 82.82% and smallest with asphalt content 5.0% by 59.96 %, 5.5% by 67.97%, 6.0% by 71.41%, and 6.5% by 74.99%. Thus it can be concluded that the 2.5% CR with % bitumen increases VITM.

This relationship between the VMA and the asphalt content is shown in Figure (4.14)

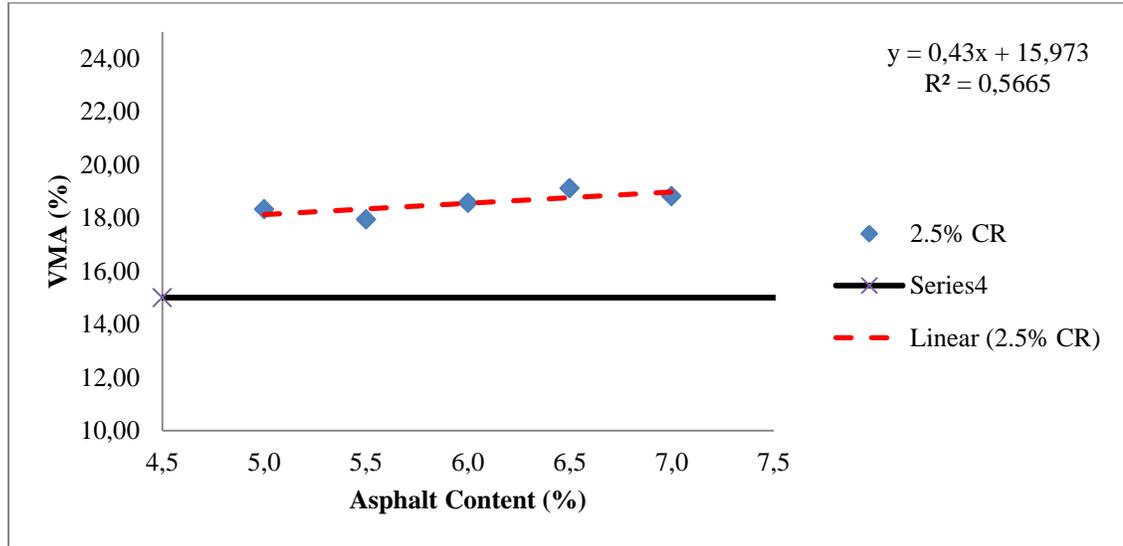


Figure 4.14. Correlation VMA and AC with 2.5% CR toward asphalt content

Through the review of the VMA results in Table 4.5 and Figure 4.14 the following observations were obtained that VMA value of asphalt concrete with crumb rubber 2.5% CR is highest with the 6.5% by 19.12% and smallest with asphalt content 5.5% by 17.94%, 6.5% by 4.79%, 6.0% by 5.32%, and 5.5% by 5.77%. Thus it can be concluded that the 2.5% CR with % bitumen decreases air void.

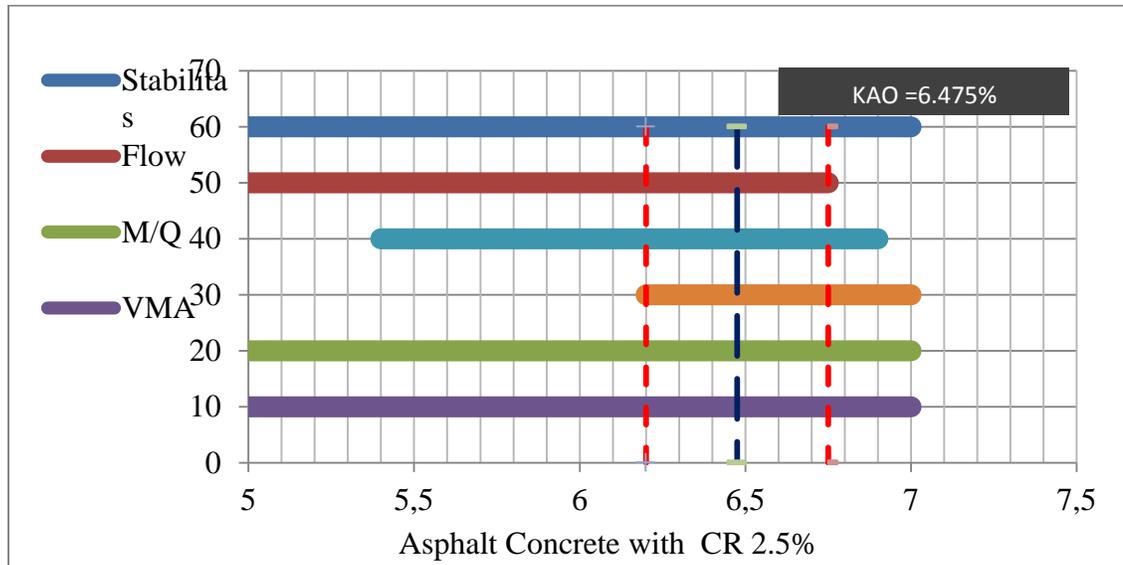


Figure 4.15. Correlation Marshall Properties toward 2.5% CR

Table 4.5 shows some properties of asphalt concrete modified with crumb rubber 2.5%.

Through the review of the Marshall Properties test results in Table 4.4 were obtained the following observations that the OBC when added crumb rubber 2.5% is 6.475% bitumen, that is shown in Figure 4.15

4.14.2. Properties of Asphalt Concrete With 5.0% Crumb Rubber.

Table 4.6. Properties of asphalt concrete with 5.0% crumb rubber (60/70)

Asphalt content (%)	Stabilities Kg	Flow mm	VFWA	Air void	MQ	Density	VMA
5.0	784.31	4.00	54.60	8.96	195.81	2.24	19.72
5.5	883.42	4.13	59.63	8.04	214.10	2.24	19.91
6.0	962.00	3.97	65.84	6.82	242.08	2.26	19.85
6.5	921.08	3.60	70.68	5.98	256.75	2.26	20.13
7.0	846.48	2.80	73.37	5.53	304.59	2.26	20.73

This relationship between the stability and the asphalt content with CR 5.0% is shown in Figure 4.16

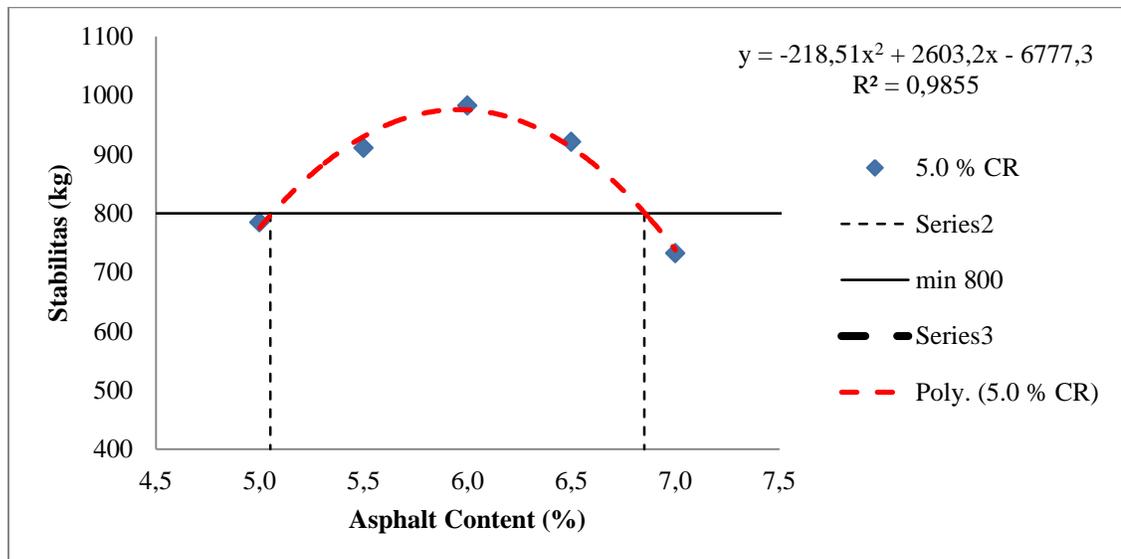


Figure 4.16. Correlation stability and AC with 5.0% CR toward asphalt content

Through the review of the stability test results in Table 4.5 and Figure 4.16 were obtained the following observations that the stability value of asphalt concrete with crumb rubber 5.0% is highest with asphalt content 6.0% by 982.68 kg and is smallest with asphalt content 7.0% by 732.02 with add the 2.5% crumb rubber effect at the cohesion and the bonding stability of modified bitumen decrease. So the stability value of asphalt concrete modified without crumb rubber is higher than asphalt concert with crumb rubber, and the stability value of asphalt concrete modified with crumb rubber 2.5% is higher than asphalt concert with crumb rubber 5.0% but the stability increases along with the decrease of CR content up to a certain extent (optimum) and decreases after it passes the optimum limit. This happens because the asphalt as the binding material between the aggregate can become a lubricant after the optimum limit as the binding.

This relationship between the flows and the asphalt content is shown in Figure 4.17.

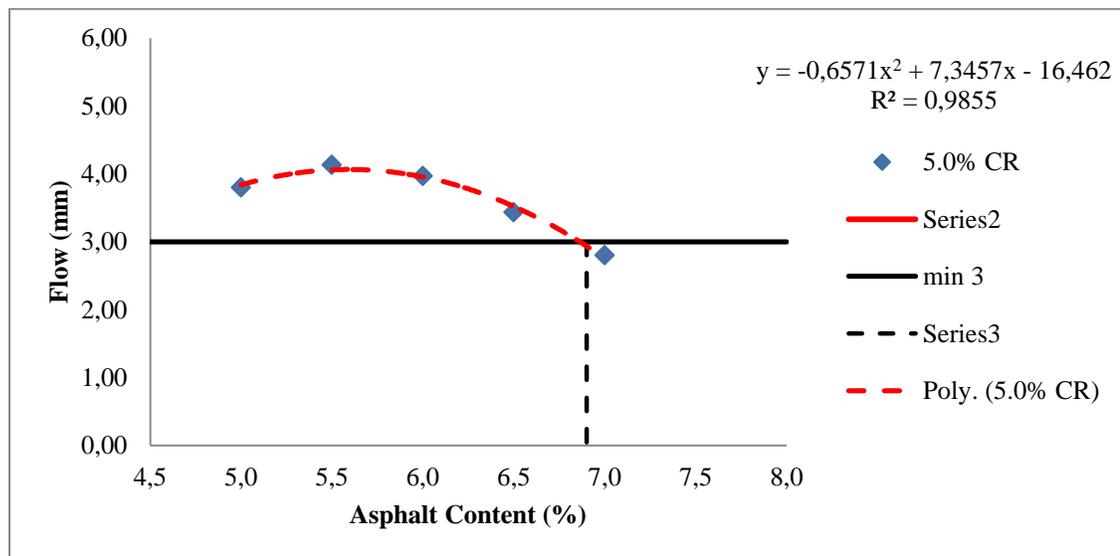


Figure 4.17. Correlation flows and AC with 5.0% CR toward asphalt content

Through the review of the flow test results in Table 4.6. and Figure 4.17. the following observations were obtained that flow value of asphalt concrete with crumb rubber 5.0% is highest with asphalt content 5.5% by 4.13 mm and smallest with asphalt content 7.0% by 2.8 mm. Thus it can be concluded that the higher the asphalt content

increases flow. With the addition of the asphalt content will affect the mixes become less flexible and the resistance to deformation decreases resulting in a high flow value.

This relationship between the marshal quotients and the asphalt content with CR 5.0% is shown in Figure 4.18

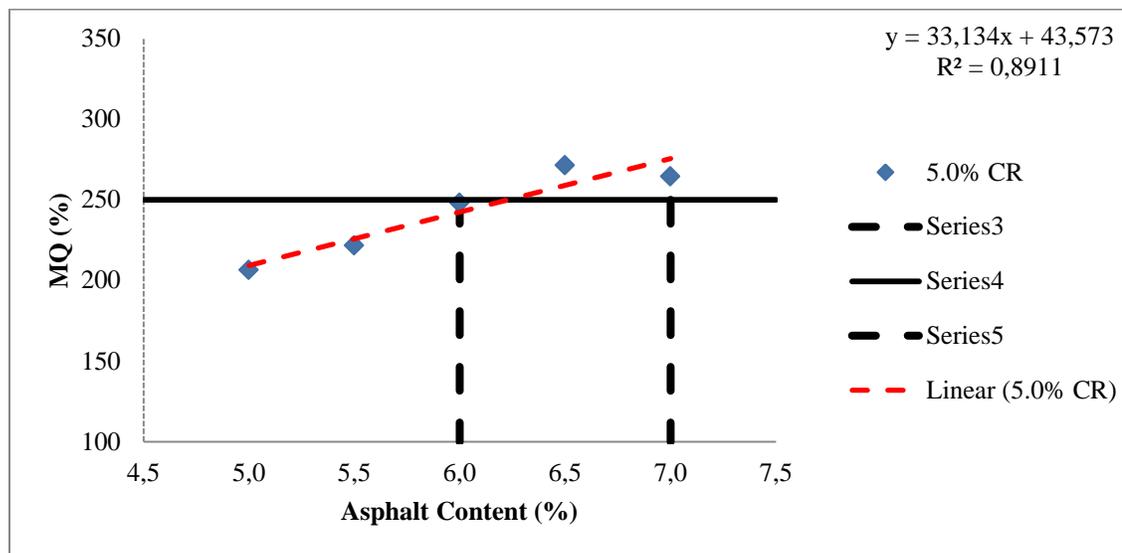


Figure 4.18. Correlation MQ and AC with 5.0% CR toward asphalt content

Through the review of the Marshall quotient test results in Table 4.6 and Figure 4.18 were obtained the following observations that Marshall Quotient value of asphalt concrete with crumb rubber 5.0% is highest with the 6.5% by 256.75 mm and smallest with asphalt content 5.0% by 195.81 mm. Thus it can be concluded that the 5.0% CR with % bitumen increases Marshall Quotient.

This relationship between the air void and the asphalt content with CR 5.0 % is shown in figure 4.19

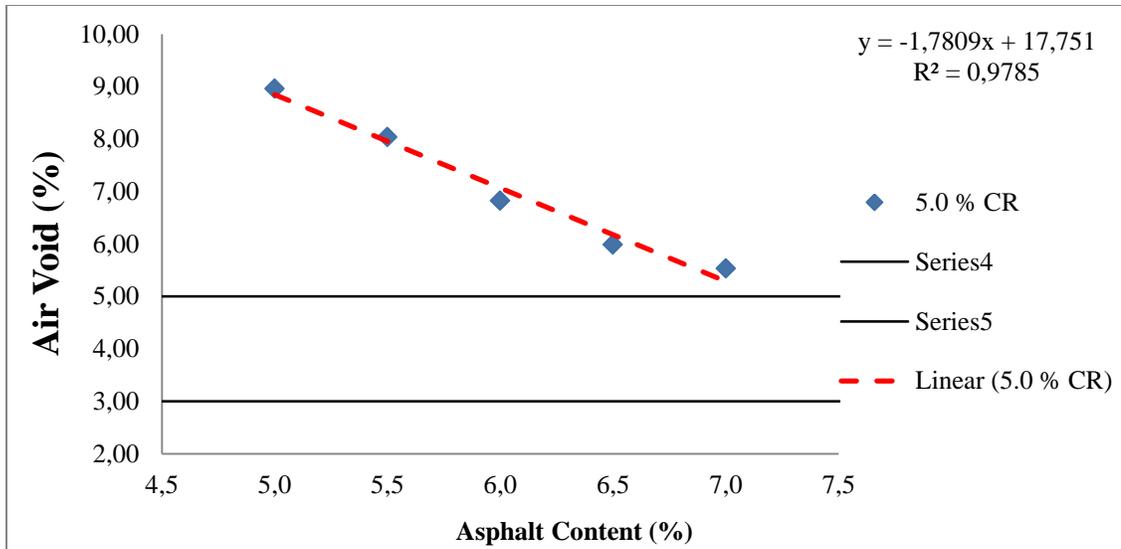
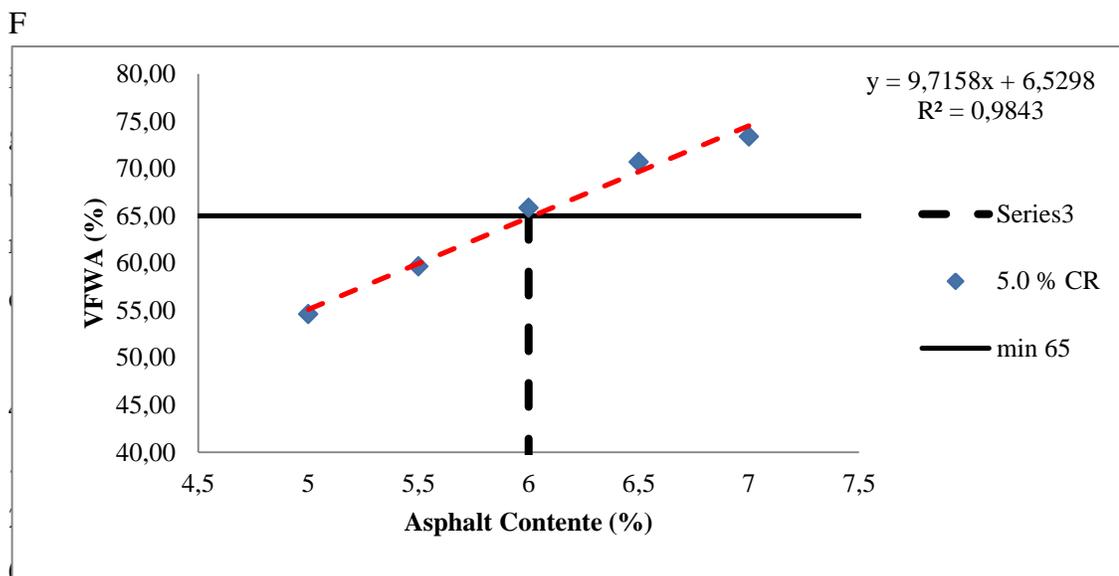


Figure 4.19. Correlation Air Void and AC with 5.0% CR toward asphalt content

Through the review of the air void test results in Table 4.6 and Figure 4.19 were obtained the following observations that air void value of asphalt concrete with crumb rubber 5.0% is highest with the 5.0% by 8.96% and smallest with asphalt content 7.0% by 5.53%. Thus it can be concluded that the 5.0% CR with % bitumen decreases air void.

This relationship between the VFWA and the asphalt content is shown in Figure 4.20



: Correlation VFWA and AC with 5.0% CR toward asphalt content

Through the review of the VFWA results in Table 4.6 and Figure 4.20 were obtained the following observations that VFWA value of asphalt concrete with crumb

rubber 5.0% is highest with the 7.0% by 73.37% and smallest with asphalt content 5.0% by 54.60%. Thus it can be concluded that the 5.0% CR with % bitumen increases VFWA.

This relationship between the VMA and the asphalt content with CR 5.0% is shown in figure 4.21

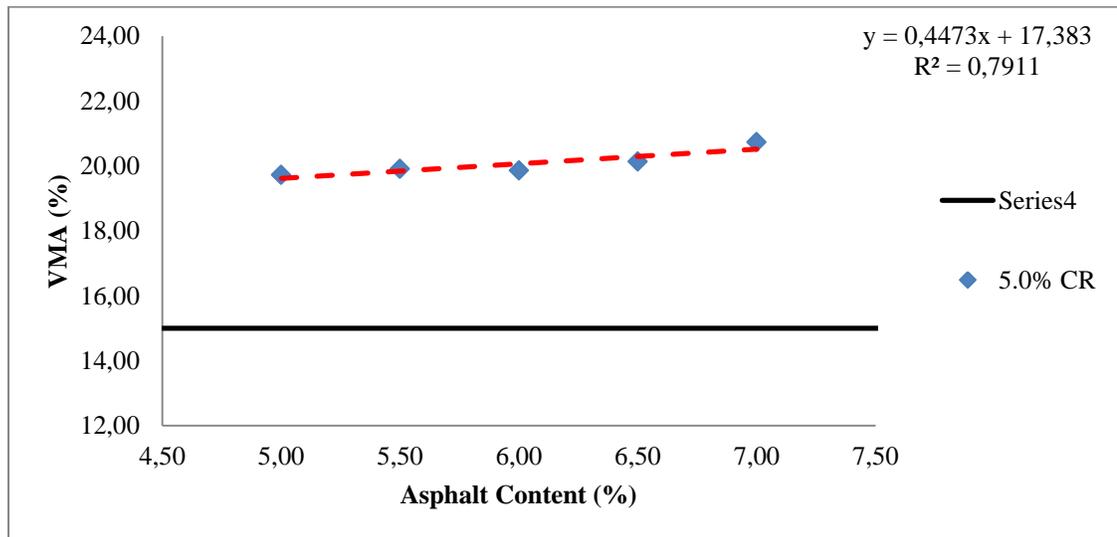


Figure 4.21. Correlation VMA and AC with 5.0% CR toward asphalt content

Through the review of the VMA results in Table 4.5 and Figure 4.21 were obtained the following observations that VMA value of asphalt concrete with crumb rubber 5.0% is highest with the 7.0% by 20.73% and smallest with asphalt content 5.0% by 19.72%. Thus it can be concluded that the 5.0% CR with % bitumen increases void mine aggregate.

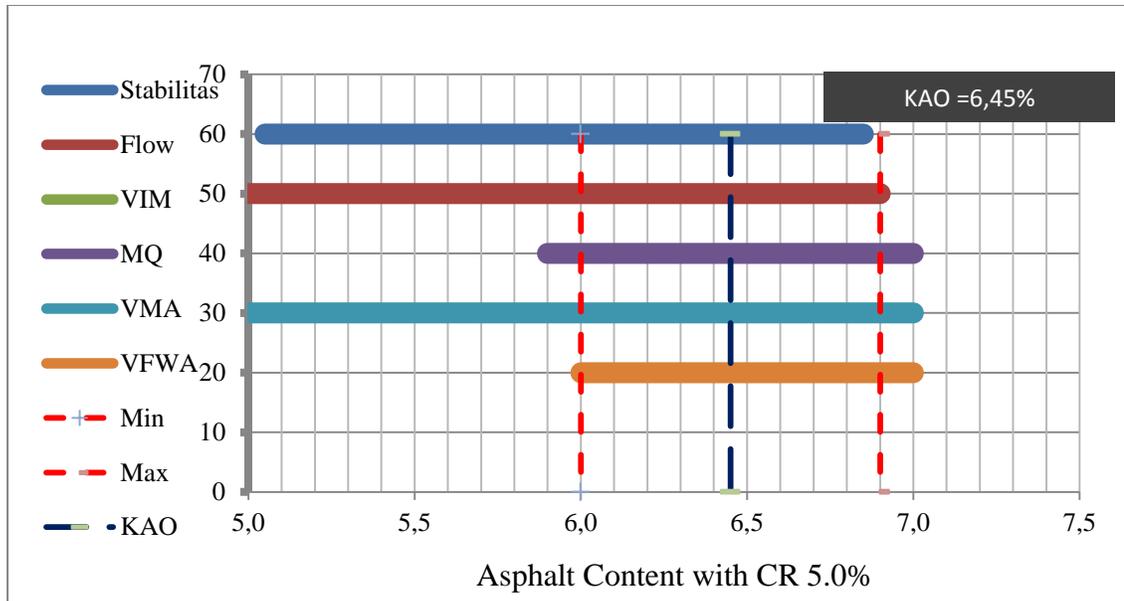


Figure 4.22. Correlation Marshall Properties toward 5.0% CR

Through the review of the Marshall Properties test results in Table 4.6 were obtained the following observations that the optimum bitumen content when added crumb rubber 5.0% is 6.45% bitumen, that is shows in Figure 4.22

4.14.3. Properties of Asphalt Concrete With 5.0% Crumb Rubber.

Table shows some properties of asphalt concrete modified with crumb rubber 5.0%.

Table 4.7. Properties of asphalt concrete with 7.5% crumb rubber (60/70)

Asphalt Content (%)	Stabilities Kg	Flow mm	VFWA	Air void	MQ	Density	VMA
5.0	747.51	4.37	58.44	7.78	171.20	2.27	18.68
5.5	884.20	4.80	64.05	6.79	184.20	2.28	18.82
6.0	940.33	5.17	70.79	5.46	182.11	2.29	18.68
6.5	924.28	4.61	79.92	3.64	200.31	2.32	18.14
7.0	809.21	3.73	93.10	1.18	216.92	2.36	17.08

This relationship between the stability and the asphalt content with CR 7.5% is shown in Figure 4.23.

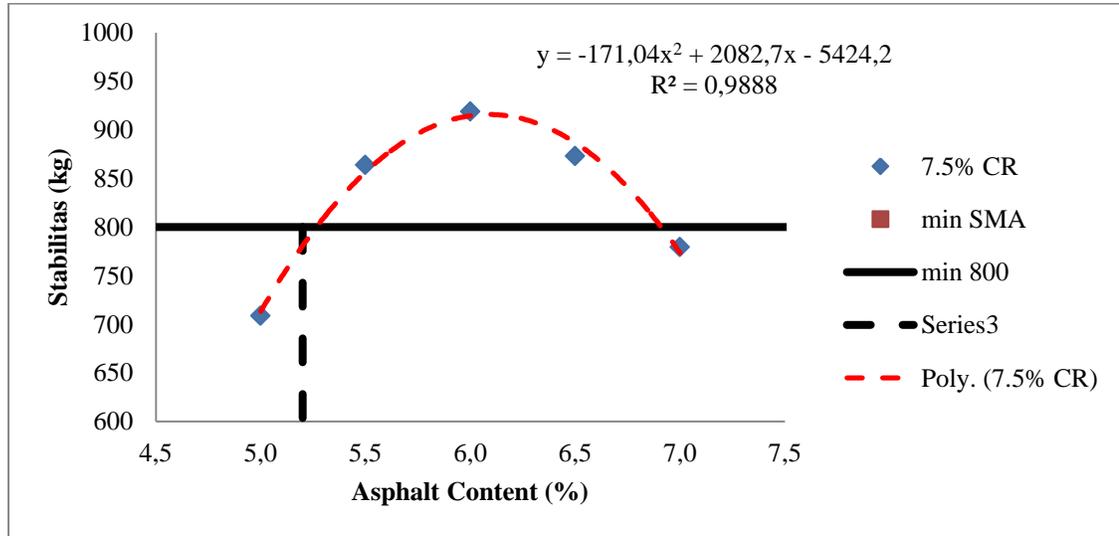


Figure 4.23. Correlation stability and AC with 7.5% CR toward asphalt content

Through the review of the stability test results in Table 4.7 and Figure 4.23 the following observations were obtained that the stability value of asphalt concrete with crumb rubber 7.5% is highest with asphalt content 6.0% by 940.33 kg and is smallest with asphalt content 5.0% by 747.51 with add the 7.5% crumb rubber effect at the cohesion and the bonding stability of modified bitumen decrease. So the stability value of asphalt concrete modified without crumb rubber is higher than asphalt concert with crumb rubber, and the stability value of asphalt concrete modified with crumb rubber 5.0% is higher than asphalt concert with crumb rubber 7.5% but the stability increases along with the decrease of CR content up to a certain extent (optimum) and decreases after it passes the optimum limit. This happens because the asphalt as the binding material between the aggregate can become a lubricant after the optimum limit as the binding.

This relationship between the flows and the asphalt content is shown in Figure 4.24.

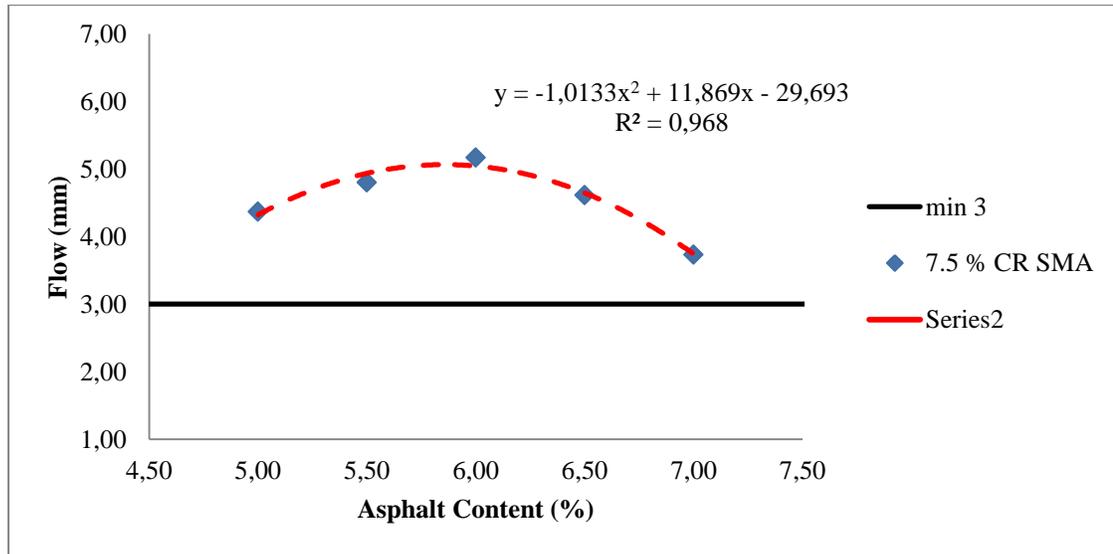


Figure 4.24. Correlation flows and AC with 7.5% CR toward asphalt content

Through the review of the flow test results in Table 4.7 and Figure 4.24 the following observations were obtained that flow value of asphalt concrete with crumb rubber 7.5% is highest with asphalt content 6.0% by 5.17 mm and smallest with asphalt content 7.0% by 3.73 mm. Thus it can be concluded that the higher the asphalt content increases flow. With the addition of the asphalt content will affect the mixes become less flexible and the resistance to deformation decreases resulting in a high flow value.

This relationship between the marshal quotients and the asphalt content with CR 7.5% is shown in Figure 4.25.

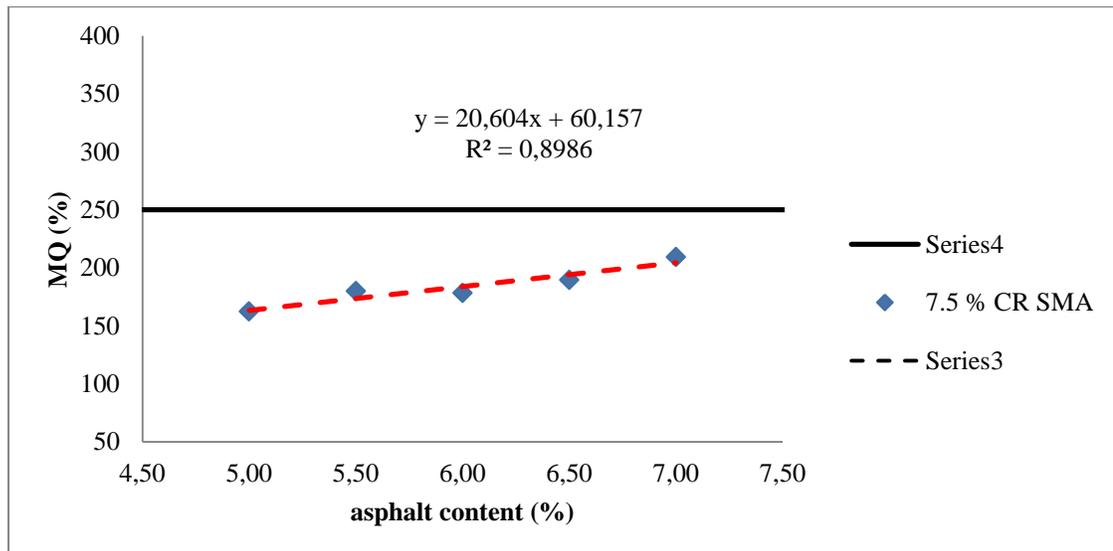


Figure 4.25. Correlation MQ and AC with 7.5% CR toward asphalt content

Through the review of the MQ test results in Table 4.7 and Figure 4.25 the following observations were obtained that MQ value of asphalt concrete with crumb rubber 7.5% is highest with the 7.0% by 216.92 mm and smallest with asphalt content 5.0% by 171.20 mm. Thus it can be concluded that the 7.5% CR with % bitumen increases MQ.

This relationship between the air void and the asphalt content with CR 7.5% is shown in Figure 4.26.

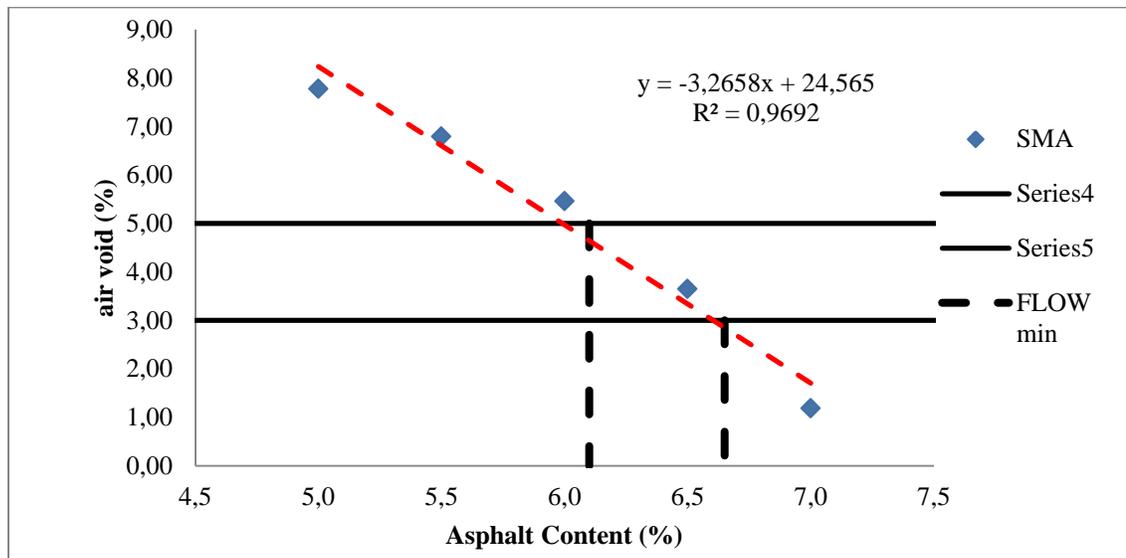


Figure 4.26. Correlation Air Voids and AC with 7.5% CR toward asphalt content

Through the review of the air voids test results in Table 4.7 and Figure 4.26 the following observations were obtained that air void value of asphalt concrete with crumb rubber 7.5% is highest with the 5.0% by 7.78% and smallest with asphalt content 7.0% by 1.18%. Thus it can be concluded that the 7.5% CR with % bitumen decreases air void.

This relationship between the VFWA and the asphalt content with crumb rubber 7.5% is shown in Figure 4.27

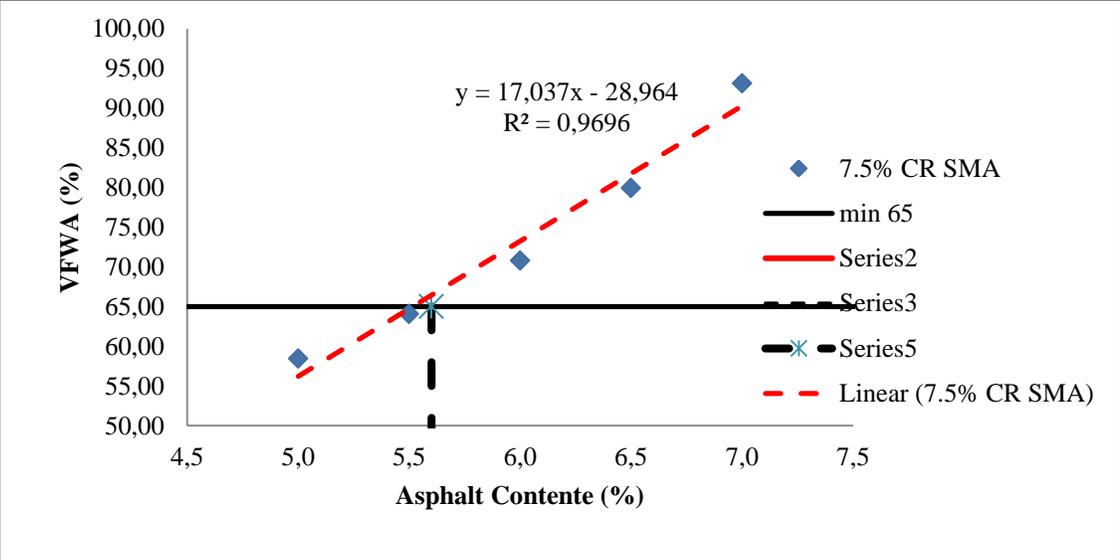


Figure 4.27. Correlation VFWA and AC with 7.5% CR toward asphalt content

Through the review of the VMA results in Table 4.7 and Figure 4.28 the following observations were obtained that VMA value of asphalt concrete with crumb rubber 7.5% is highest with the 5.5% by 18.82% and smallest with asphalt content 7.0% by 17.08%. Thus it can be concluded that the 7.5% CR with % bitumen increases VMA..

This relationship between the VMA and the asphalt content with CR 7.5% is shown in Figure 4.28.

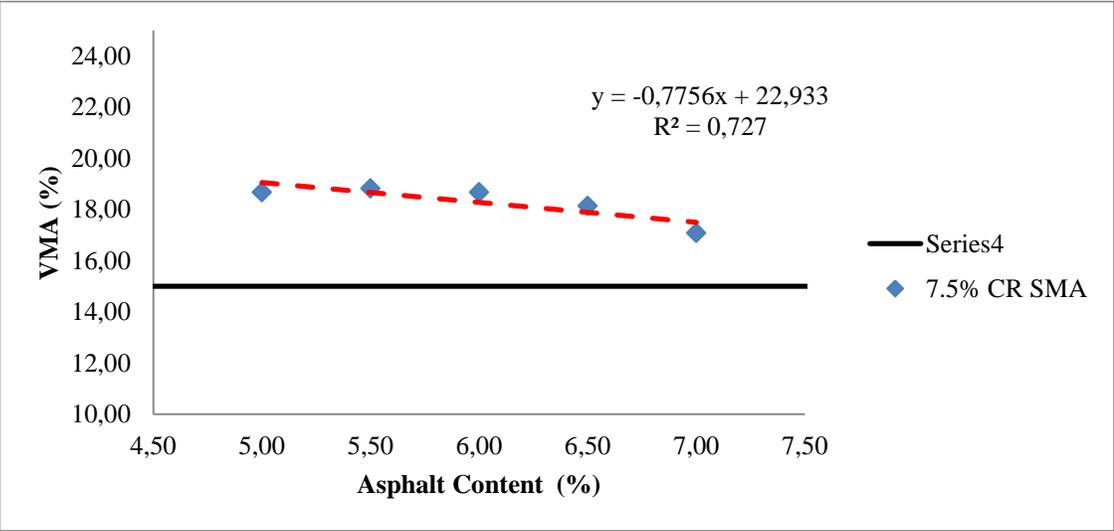


Figure 4.28. Correlation VMA and AC with 7.5% CR toward asphalt content

Through the review of the VMA results in Table 4.7 and Figure 4.28 the following observations were obtained that VMA value of asphalt concrete with crumb rubber 7.5% is highest with the 5.5% by 20.73% and smallest with asphalt content 17.08% by 19.72%. Thus it can be concluded that the 7.5% CR with % bitumen increases VMA.

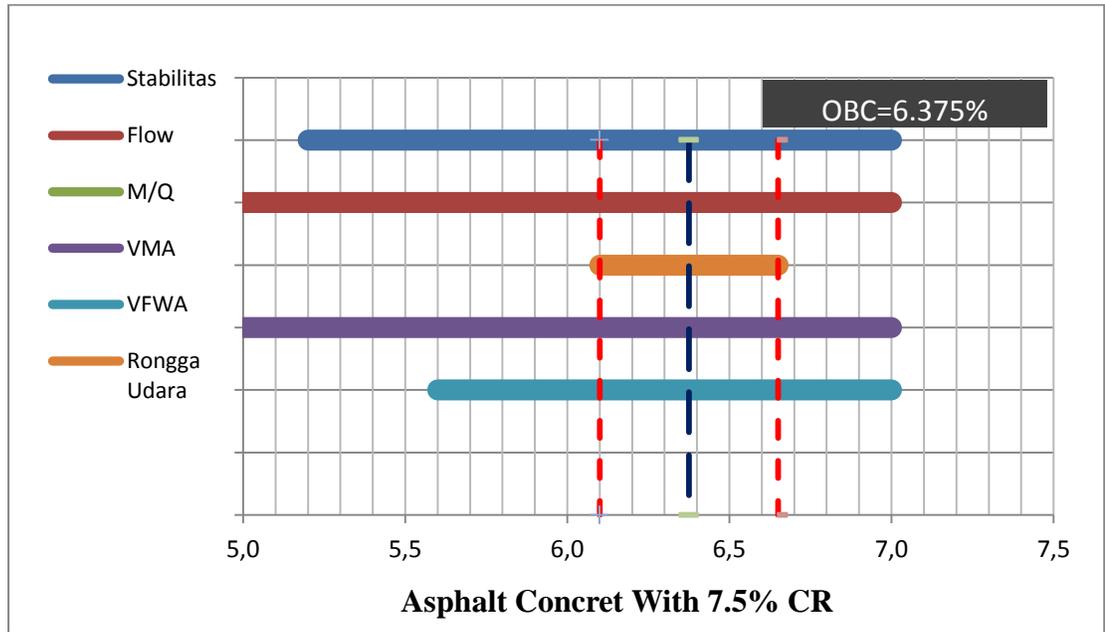


Figure 4.29. Correlation Marshall Properties toward 7.5% CR

Through the review of the Marshall Properties test results in Table 4.7 the following observations were obtained that the OBC when added crumb rubber 7.5% is 6.375% bitumen, that is shows in Figure 4.29

4.14.4. Properties of Asphalt Concrete With 10% Crumb Rubber.

Table 4.8. Properties of asphalt concrete with 10 % crumb rubber (60/70)

Asphalt Content (%)	Stabilities Kg	Flow mm	VFWA	VIM	MQ	Density	VMA
5.0	731.87	5.03	46.82	11.84	146.51	2.17	22.26
5.5	769.38	5.03	49.94	11.46	154.23	2.16	22.89
6.0	774.43	5.35	56.41	9.77	145.44	2.19	22.39
6.5	718.15	5.13	57.26	10.10	139.83	2.16	23.62
7.0	649.58	6.13	56.94	11.02	107.05	2.13	25.34

This relationship between the stability and the AC with CR 10% is shown in Figure 4.30

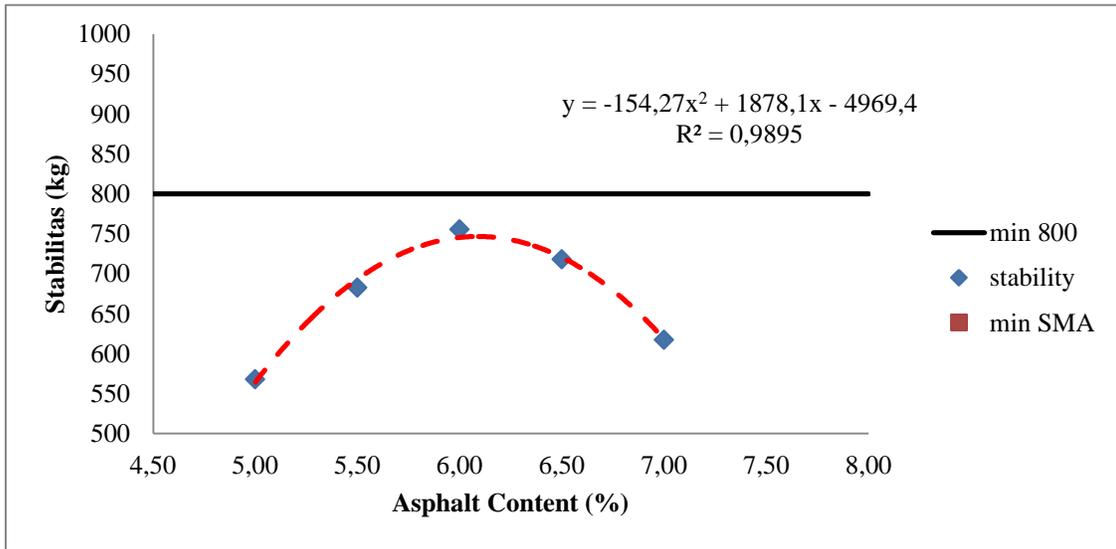


Figure 4.30. Correlation stability and AC with 10% CR toward asphalt content

Through the review of the stability test results in Table 4.8 and Figure 4.30 the following observations were obtained that the stability value of asphalt concrete with crumb rubber 10% is highest with asphalt content 6.0% by 774.43 kg and is smallest with asphalt content 5.0% by 649.58 with by adding the 10% crumb rubber effect at the cohesion and the bonding stability of modified bitumen decrease. So the stability value of asphalt concrete modified without crumb rubber is higher than asphalt concert with crumb rubber, and the stability value of asphalt concrete modified with crumb rubber 7.5 % is higher than asphalt concert with crumb rubber 10 % but the stability increases along with the decrease of CR content up to a certain extent (optimum) and decreases after it passes the optimum limit. This happens because the asphalt as the binding material between the aggregate can become a lubricant after the optimum limit as the binding.

This relationship between the flows and the asphalt content is shown in Figure 4.31

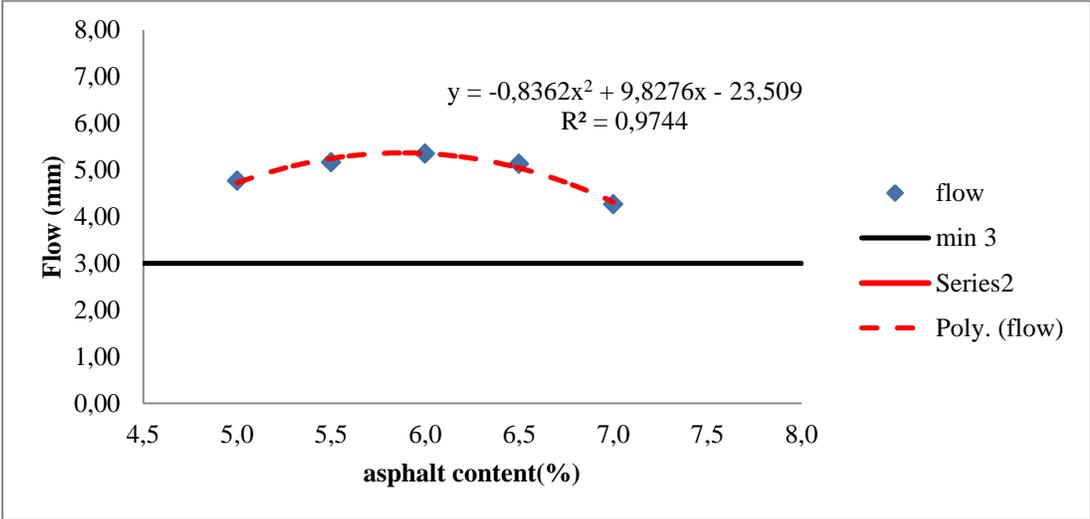


Figure 4.31. Correlation Flows and AC with 10% CR toward asphalt content

Through the review of the flow test results in Table 4.8 and Figure 4.31 the following observations were obtained that flow value of asphalt concrete with crumb rubber 10 % is highest with asphalt content 7.0 % by 6.13 mm and smallest with asphalt content 5.0% by 5.03 mm. Thus it can be concluded that the higher the asphalt content increases flow. With the addition of the asphalt content will affect the mixes become less flexible and the resistance to deformation decreases resulting in a high flow value.

This relationship between the marshal quotients and the asphalt content with CR 10% is shown in Figure 4.32.

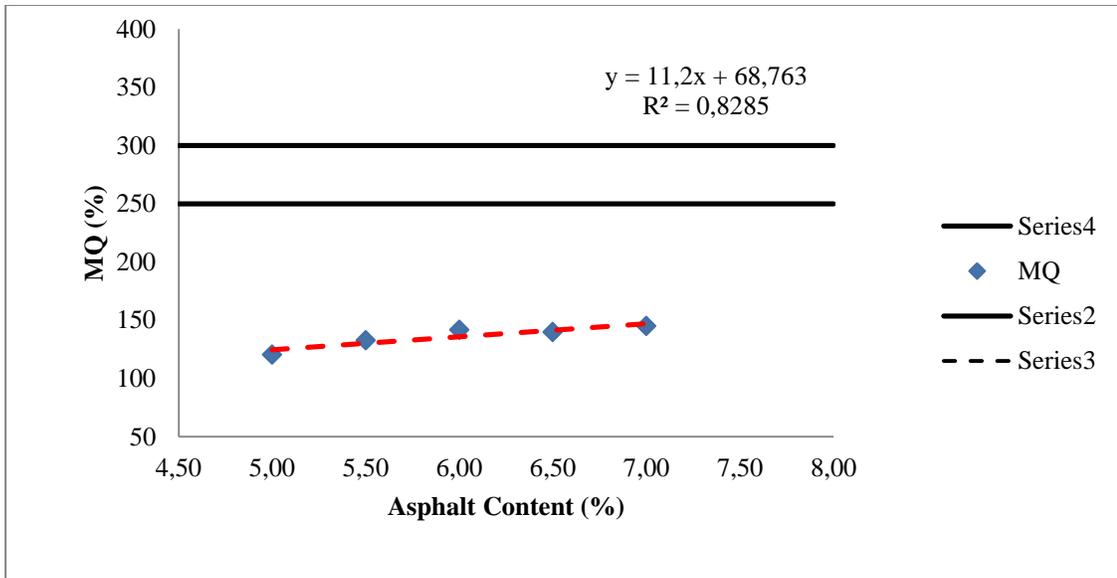


Figure 4.32. Correlation MQ and AC with 10% CR toward asphalt content

Through the review of the MQ test results in Table 4.8. and Figure 4.32. were obtained the following observations that Marshall Quotient value of asphalt concrete with crumb rubber 10 % is highest with the 5.5 % by 154.23 mm and smallest with asphalt content 7.0% by 107.05 mm. Thus it can be concluded that the 10% CR with % bitumen decreases Marshall Quotient.

This relationship between the air voids and the asphalt content with CR 10% is shown in Figure 4.33.

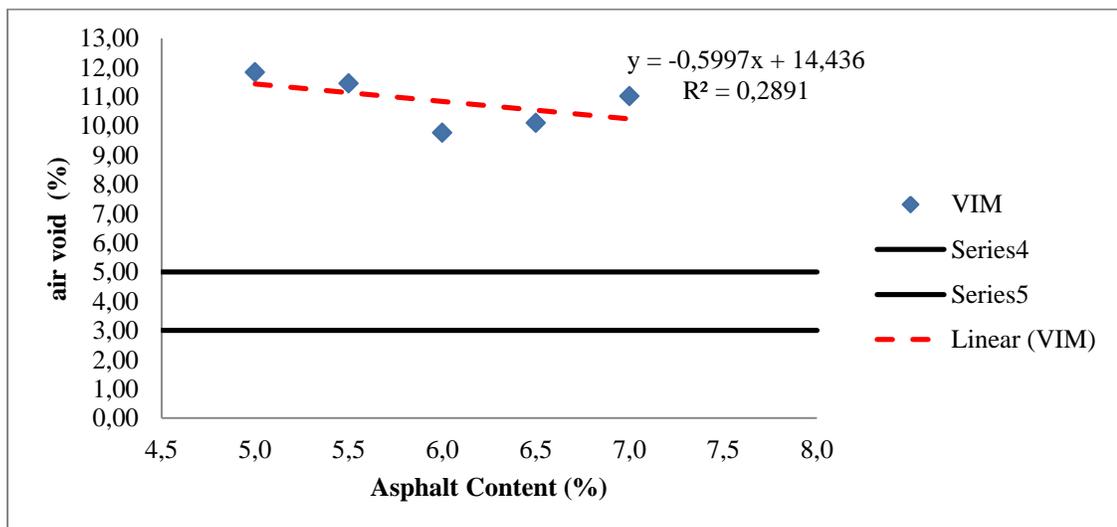


Figure 4.33. Correlation Air Voids and AC with 10% CR toward asphalt content

Through the review of the air void test results in Table 4.8 and Figure 4.33 the following observations were obtained that air void value of asphalt concrete with crumb rubber 10% is highest with the 5.0% by 7.78% and smallest with asphalt content 7.0% by 1.18%. Thus it can be concluded that the 10 % CR with % bitumen decreases air void.

This relationship between the VFWA and the asphalt content with crumb rubber 10 % is shown in Figure 4.34.

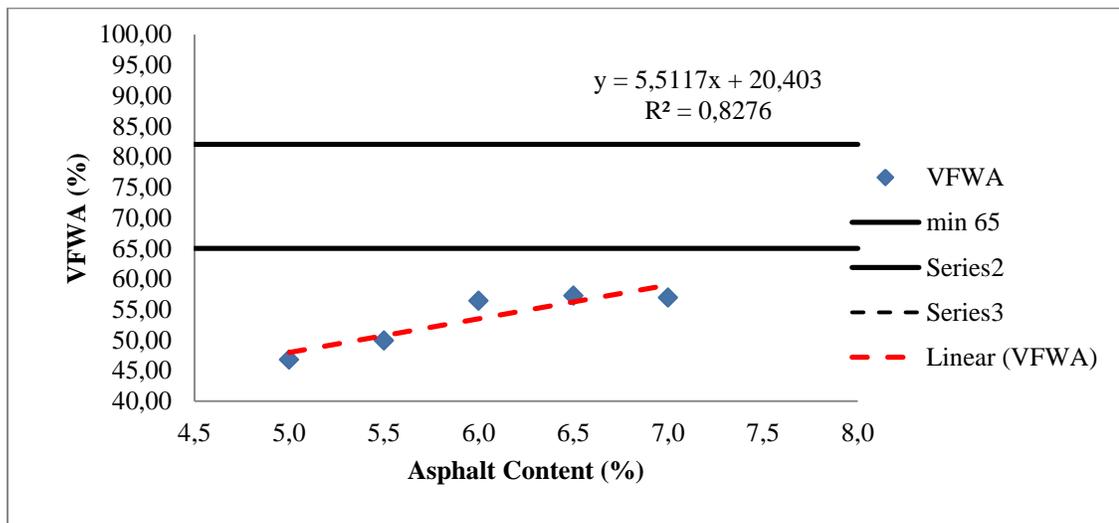


Figure 4.34. correlation VFWA and AC with 10% CR toward asphalt content

Through the review of the VFWA results in Table 4.8. and Figure 4.34. the following observations were obtained that VFWA value of asphalt concrete with crumb rubber 10% is highest with the 7.0% by 56.94% and smallest with asphalt content 5.0% by 46.82%. Thus it can be concluded that the 10% CR with % bitumen increases VFWA.

This relationship between the VMA and the asphalt content with CR 10% is shown in figure 4.35.

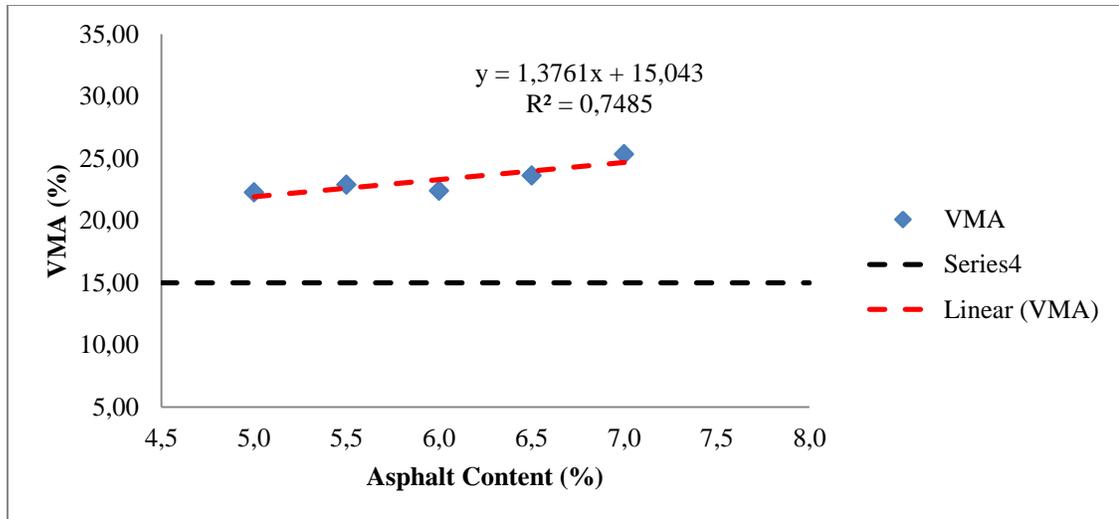


Figure 4.35. Correlation VMA and AC with 10% CR toward asphalt content

Through the review of the VMA results in Table 4.8. and Figure 4.35. the following observations were obtained that VMA value of asphalt concrete with crumb rubber 10% is highest with the 7.0% by 25.34% and smallest with asphalt content 5.0% by 22.26%. Thus it can be concluded that the 10% CR with % bitumen increases void mine aggregate.

4.15.

Comparison of Marshall Test

Table.4.9. Comparison of Stability of AC modified with and without crumb rubber

Asphalt Content	Stability 0% CR	Stability 2.5% CR	Stability 5.0% CR	Stability 7.5% CR	Stability 10 % CR
5.00	1035.33	896.78	784.31	747.51	731.87
5.50	1336.90	1056.50	883.42	884.20	769.38
6.00	1412.80	1181.26	962.00	901.33	774.43
6.50	1328.01	1172.59	921.08	900.28	718.15
7.00	1166.02	1029.50	846.48	809.21	649.58

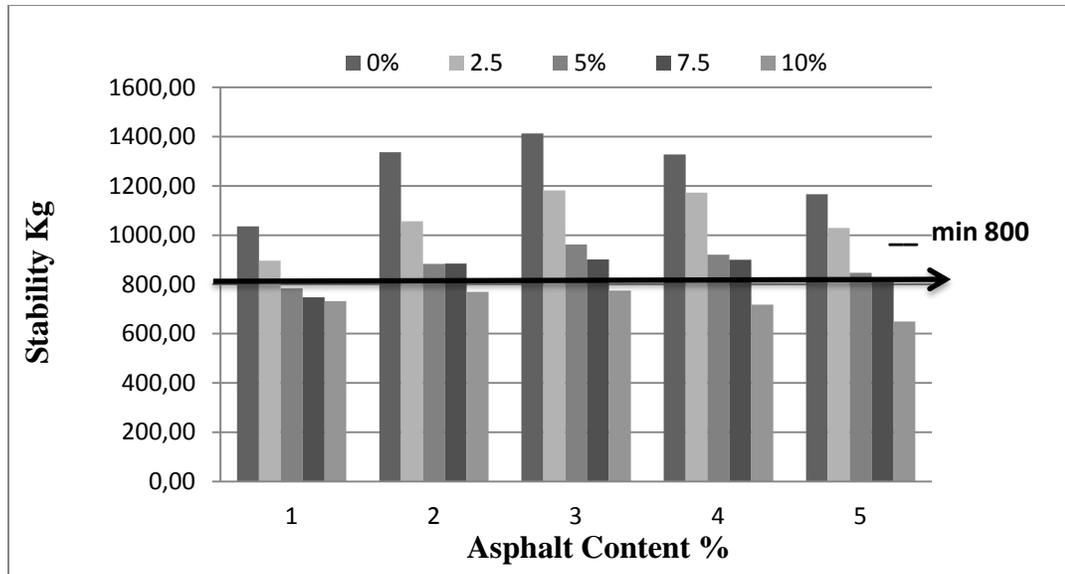


Figure 4.36. Comparison of Stability test for AC with and without CR

A. Stability Test

Through the comparison of the stability test results in Table 4.9 and Figure 4.36 it was obtained that the asphalt concrete without crumb rubber with asphalt content 6% has optimum stability value of 1412.80 kg. On the other hand, AC modified with 2.5% CR has optimum stability value of 1181.26 kg at 6.0% asphalt content; AC modified with 5% CR has optimum stability value of 962.0 kg at 6.5% asphalt content. AC modified with 7.5% CR has optimum stability value of 901.33 kg at 6.0% asphalt content. AC modified with 10% CR has optimum stability value of 769.38 kg at 5.5% asphalt content. Thus it can be concluded that the higher crumb rubber percent decreases stability. Further injection of crumb rubber into the mixture led to a decrease in the value of stability because application of excessive crumb rubber decreases the coarse aggregate contact point within the mixture. The addition of crumb rubber will give higher penetration or softer asphalt. As a result, the mixture becomes more flaccid so as to contribute to the decrease in the value of stability. Low stability suggests low quality of aggregates. The stability of aggregates decreases with an increase in crumb rubber content (Mashaan *et al.* 2013). It was found that increasing the crumb rubber reduces the stability of AC, with higher percent of crumb rubber yielding in lowest stability value. However, Al-Qadi *et al.*

(2009) reported that crumb rubber has more effect on performance of asphalt mixture by increasing the Marshal Stability and Flow.

Table.4.10. Comparison of Flow of AC modified with and without crumb rubber

Asphalt Content	Flow 0%CR	Flow 2.5%CR	Flow 5.0% CR	Flow 7.5% CR	Flow 10% CR
5.00	2.80	3.00	4.00	4.37	5.03
5.50	3.22	3.53	4.13	4.80	5.03
6.00	3.40	3.80	3.97	5.17	5.35
6.50	3.17	3.47	3.60	4.61	5.13
7.00	2.67	2.80	2.80	3.73	6.13

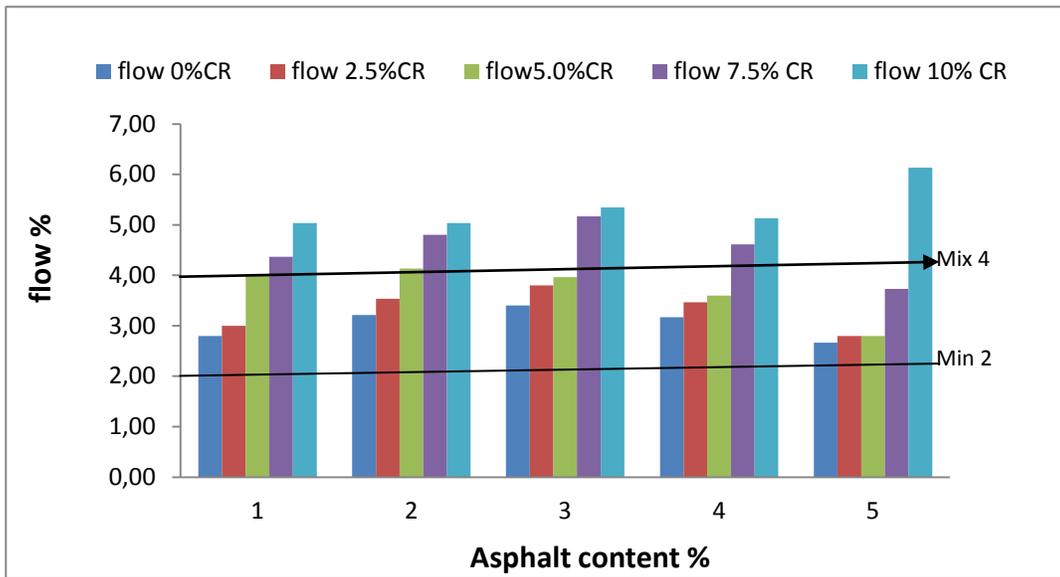


Figure 4.37. Comparison of flow test for AC with 0, 2.5, 5.0, 7.5 and 10% CR

B. Flow

Through the comparison of the Flows test results in Table 4.10 Figure 4.37 it was found that flow test value of asphalt concrete increased as the crumb rubber content increased from 0% to 7%. Higher flow values may be related to the increase of air voids (more compaction required) by using more CRM in the mixture, which leads to a more flexible mixture.

Thus it can be concluded that the higher the crumb rubber content increased flow but higher asphalt content decreases flow. With the addition of the asphalt content the mixes become more flexible and the resistance to deformation decreases resulting in a high flow value. Mashaan et al. (2013) similarly reported that the addition of crumb rubber modifier to asphalt concrete increases the flow of the mixture until optimum crumb rubber content is reached.

C. Void Filled With Asphalt (VFWA)

The analysis of the VFWA test results in Figure 4.38 showed that modified with 0%, 2.5%, 5.0%, 7.5% and 10% CR have maximum VFWA values of 80.60, 82.82, 73.37, 93.10, and 56.94, respectively. Thus it can be concluded that increase in percent of crumb rubber content increases the VFWA. The reason is that voids provide spaces for the movement of the asphalt cement or asphalt rubber binder within the compacted mix. Mix design of asphalt and rubberized AC asphalt paving mixes is a trade-off between high binder content to enhance long term durability and performance, and sufficient in-place void space to avoid rutting, instability, flushing and bleeding, as it is clearly shown in Table 4.11 the VFWA.

Table 4.11. Comparison of VFWA of AC modified with and without crumb rubber

Asphalt Content	VFWA 0%CR	VFWA 2.5%CR	VFWA 5.0%CR	VFWA 7.5% CR	VFWA 10% CR
5.00	61.44	59.96	54.60	58.44	46.82
5.50	66.89	67.97	59.63	64.05	49.94
6.00	70.31	71.41	65.84	70.79	56.41
6.50	75.92	74.99	70.68	79.92	57.26
7.00	80.60	82.82	73.37	93.10	56.94

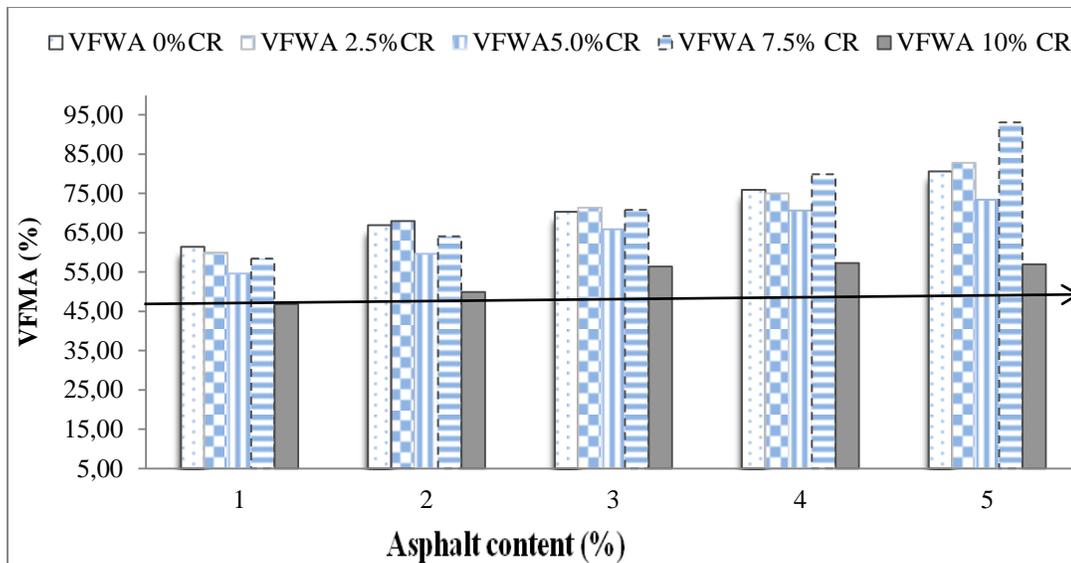


Figure 4.38. Comparison of VFWA test for AC with and without CR

D. Voids In Mix (VIM) Test

Through the comparison of the Voids In Mix test results in Table 4.12. Figure 4.39. it was found that the Voids in Mix value of asphalt concrete without crumb rubbers is 6.91. at asphalt content of 5%, while AC modified with 2.5%, 5.0%, 7.5%, and 10% CR have maximum Voids In Mix value of 7.37, 8.96, 7.78 and 11.84, respectively asphalt content 5%. Thus it can be concluded that higher crumb rubber and asphalt content increase Voids in Mix. This is supported by Ibrahim et al. (2014) which found that crumb rubber particle size can affect the optimum binder content for open graded friction course. The durability of HMA is a function of the VIM or porosity. In general, the higher the porosity, the less permeable will be the mixture and vice versa. Too much voids in the mix (high porosity) will provide passageways through the mix for the entrance of damaging air and water. Too low porosity could lead to flushing where the excess bitumen squeezes out of the mix to the surface. However, Al-Qadi et al., (2009)

Table.4.12. Comparison of VIM of AC modified with and without crumb rubber

Asphalt Content	VIM 0%CR	VIM 2.5%CR	VIM 5.0%CR	VIM 7.5% CR	VIM 10% CR
5.00	6.91	7.37	8.96	7.78	11.84
5.50	6.14	5.77	8.04	6.79	11.46
6.00	5.59	5.32	6.82	5.46	9.77
6.50	4.65	4.79	5.98	3.64	10.10
7.00	3.73	3.23	5.53	1.18	11.02

This relationship between VIM of the asphalt concrete AC and asphalt concrete modified with crumb rubber is shown in figure 4.39.

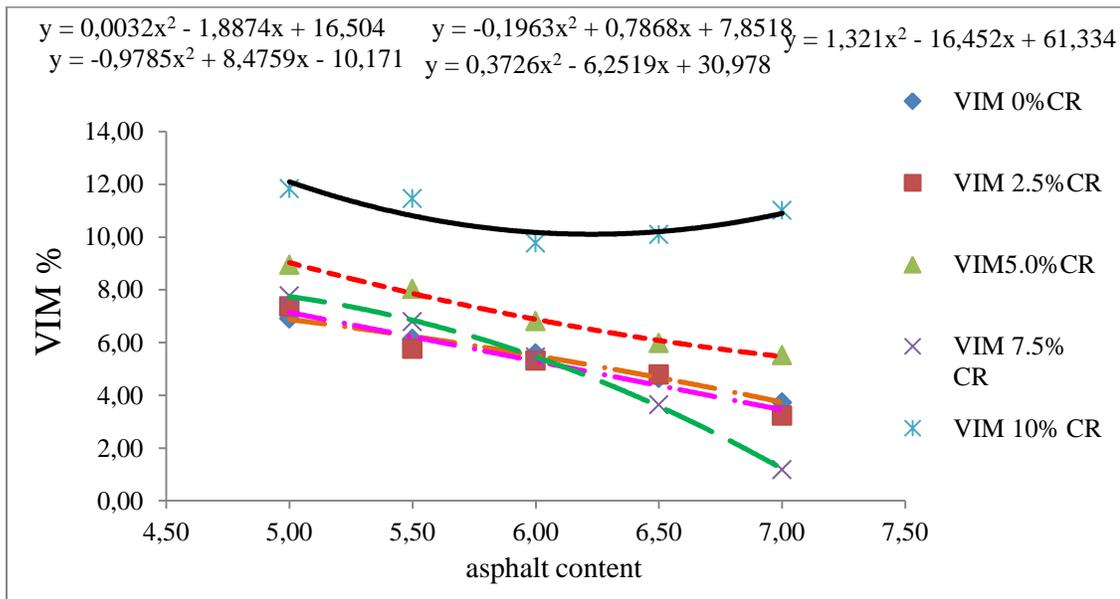


Figure 4.39. Comparison of VIM test for AC with and without CR

4.16. Indirect Tensile Strength Test (ITS)

The strength test was used to determine tensile strength and strain of the mixture specimens. Specimens were monotonically loaded to failure along the vertical diametric axis at the constant rate of 3 in/min (76.2 mm/min)

The indirect tensile strength test is one type of tensile strength test used for stabilized materials. This test involves loading a cylindrical specimen with a compressive

load along two opposite generators. This results in a relatively uniform tensile stress acting perpendicular to and along the demurral plan of the applied load this result in splitting failure generally occurring along the diametric plans three samples for each type of asphalt concrete without and with CR were tested at temperatures 30°C, 40°C and 60°C.

Figure 4.40. and Table 4.13. shows the summarized result of indirect tensile strength test each type of asphalt concrete without and with crumb rubber in OBC.

Calculate the tensile strength of the compacted bituminous mixture:

$$ITS = \frac{2F}{3.14(h.d)} \quad (4.1)$$

Where:

ITS: is Indirect tensile strength, psi

F: is Total applied vertical load at failure, lb

∴ F = 2708.14 KN

h: is Height of specimen, in = 63.37mm

d: is Diameter of specimen, = 100 mm

$$ITS = \frac{2 \times 1000 \times 2708.14}{3.14(100 \times 63.37)} = 272 \text{ MP/mm}^2$$

$$ITS = 272 \text{ MP/mm}^2$$

Table 4.13. Comparison of indirect tensile strength test at OBC

AC type	OBC	ITS @30 C (MPa)	ITS @ 40C (MPa)	ITS @ 60C (MPa)
without CR	6.4	242.23	117.81	42.40
with CR 2.5%	6.475	144.45	76.03	17.31
with CR 5.0%	6.45	129.10	52.84	10.95
with CR 7.5%	6.375	100.21	43.55	9.89

This relationship between the ITS and the different temperatures is shown in Figure 4.39.

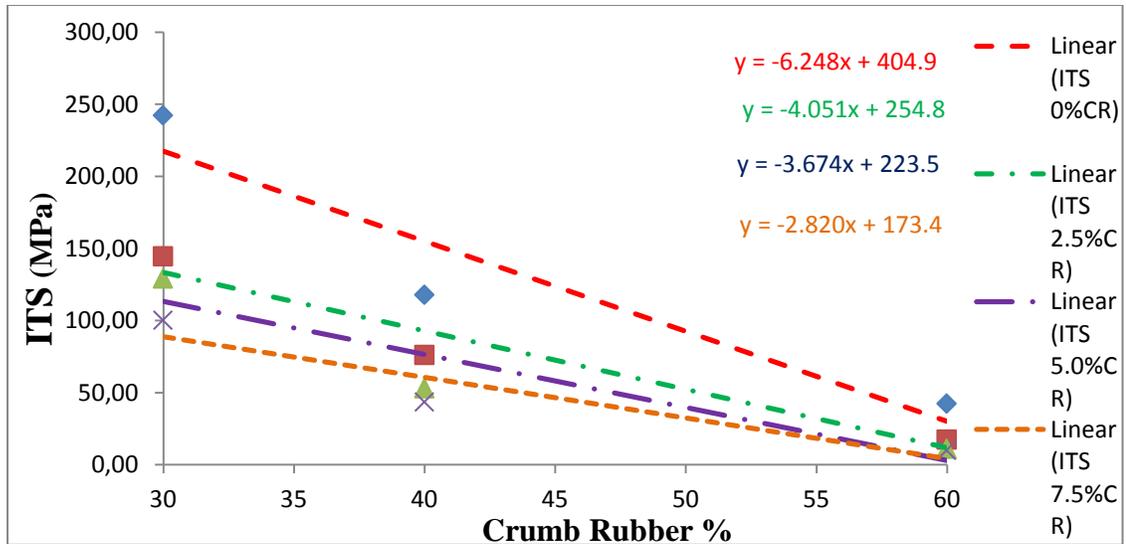


Figure 4.40. Results of ITS each and asphalt concrete modified without and with CR

Through review of the results of ITS test in Table 4.9 and Figure 4.40. the observations were obtained as the following

1. At Temperature 30°C

The ITS value of asphalt concrete without crumb rubber is higher than asphalt concrete modified without crumb rubber by 242.23MPa and asphalt concrete with 2.5% CR is higher than asphalt concrete with 5.0% by 144.45MPa, and asphalt concrete with 5.0% CR is higher than asphalt concrete with 7.5% CR by 129.10MPa. The least ITS value at a temperature 30°C was obtained for AC modified with 7.5% CR by 100.21MPa. Thus it can be concluded that asphalt concrete with crumb rubber is more sensitive to temperature changes by using ITS test compared with asphalt concrete without crumb rubber.

2. At Temperature 40°C

The ITS value of asphalt concrete without crumb rubber is higher than asphalt concrete modified without crumb rubber by 117.81MPa and asphalt concrete with 2.5% CR is higher than asphalt concrete with 5.0% by 76.03MPa, and asphalt concrete with 5.0% CR is higher than asphalt concrete with 7.5% CR by 52.84MPa. The least ITS value at a temperature 30°C was obtained for AC modified with 7.5% CR by 43.55MPa. Thus it can be concluded that asphalt concrete with crumb rubber is more sensitive to

temperature changes by using ITS test compared with asphalt concrete without crumb rubber.

3. At Temperature 60°C

The ITS value of asphalt concrete without crumb rubber is higher than asphalt concrete modified without crumb rubber by 42.4 MPa and asphalt concrete with 2.5% CR is higher than asphalt concrete with 5.0% by 17.31 MPa, and asphalt concrete with 5.0% CR is higher than asphalt concrete with 7.5% CR by 10.95 MPa. The least ITS value at a temperature 30°C was obtained for AC modified with 7.5% CR by 9.89 MPa. Thus it can be concluded that asphalt concrete with crumb rubber is more sensitive to temperature changes by using ITS test compared with asphalt concrete without crumb rubber.

Through the above observation for asphalt concrete mixtures that is stronger than the asphalt mixture with crumb rubber, and asphalt concrete modified with 2.5% crumb rubber is stronger than the asphalt concrete modified with 5.0% and 7.5% crumb rubber. There are a lot of filler composition of the asphalt so it can fill cavities in the asphalt mix aggregate and asphalt than surrounds thicker than using asphalt without crumb rubber. The asphalt concrete modified with crumb rubber is more sensitive to temperature changes by using ITS test compared with asphalt concrete without crumb rubber.

4.17. Unconfined Compressive Strength Test (UCS)

This test used to determine the resistance to permanent deformation of bitumen mixture at 30°C and loads. It is conducted by applying a static load to a specimen using OBC and then measuring the maximum load. This test used to determine the permanent deformation of asphalt concrete without crumb rubber and asphalt concrete with three type crumb rubber is done using UTM (Universal Testing Machine) to obtained strong push by the unit KN, and then a strong press is made to the calculation unit KPa. The unconfined compression test is by far the most popular method of shear testing because it is one of the fastest and cheapest methods of measuring shear strength. The results of the unconfined compressive strength test are given in Table 4.14. and Figure 4.41.

Table.4.14. Comparison of Unconfined compressive strength test at OBC at 30°C

Crumb Rubber	Load KPa @ 30°C	OBC
0	5220.707633	6.4
2.5	4097.285707	6.475
5	3234.877943	6.45
7.5	2619.054288	6.375

This relationship between the UCS and the CR is shown in Figure 4.41.

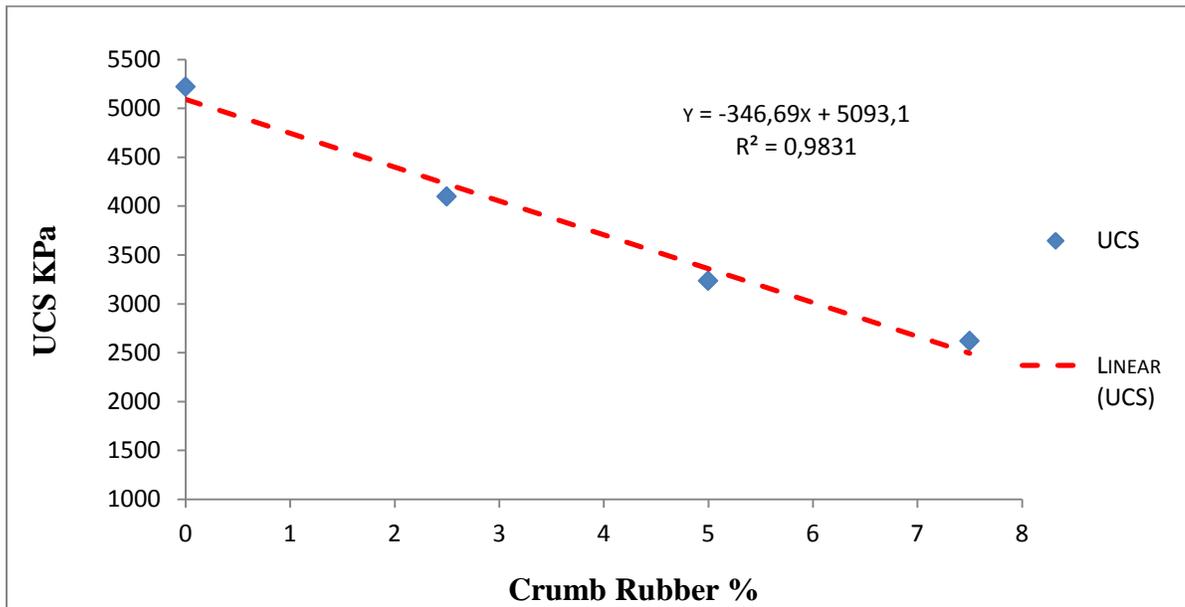


Figure 4.41 Results of UCS each and AC modified without and with CR at 30° C

Calculate the tensile strength of the compacted bituminous mixture:

$$F = \frac{P}{A} \quad (4.2)$$

Where:

F : is compressive strength, lbs/in² (KN/m²)

P : is maximum load, lbf (KN) = 37.72KN
 $37.72 \times 1000 = 37720\text{N}$

A : is cross sectional area, in² (m²) = 7883.98

$$F = \frac{37720 \times 1000}{7883.98} = 480.3\text{N/mm}^2$$

The UCS value of asphalt concrete 60/70 without crumb rubber is higher by 5220.71 KPa than asphalt concrete modified with crumb rubber at temperature 30°C. This is due to the addition of the asphalt concrete mixture with crumb rubber decrease adhesion of asphalt to aggregate more resistant to destruction of which would affect the decrease in UCS value. However, asphalt concrete modified without crumb rubber is higher than asphalt concrete modified with crumb rubber at temperature 30°C. The asphalt with crumb rubber is less sensitive to temperature changes by using test compared asphalt without crumb rubber. Through the study of the relationship between the value of UCS and temperature change, it is found that unmodified asphalt concrete is more sensitive to heat than crumb rubber modified AC.

4.18. Indirect Tensile Strength Modulus (ITSM)

ITSM test was performed both on samples of thin normal and modified AC using UMMATTA. Tests were conducted at a temperature of 40°C and the results can be seen in Table 4.15. and Figure 4.42. (see also Appendix D).

Table 4.15. Comparison of Indirect Tensile Strength Modulus test at 40°C

CR%	OBC	ITSM (MPa) at 40°C			Average (MPa)
0%	6.4	633	705	669	669
2.50%	6.475	613	586	599.5	599.5
5.00%	6.45	363	349	356	356
7.50%	6.375	194	234	214	214

Three samples were tested for each unmodified and modified mixture. To obtain a stiffness modulus for a mixture, each sample was tested in three different conditions and the average value was adopted. Stiffness modulus of the mixtures is shown in Table 4.42 and Figure 4.42.

This relationship between the ITSM and the CR is shown in Figure 4.42.

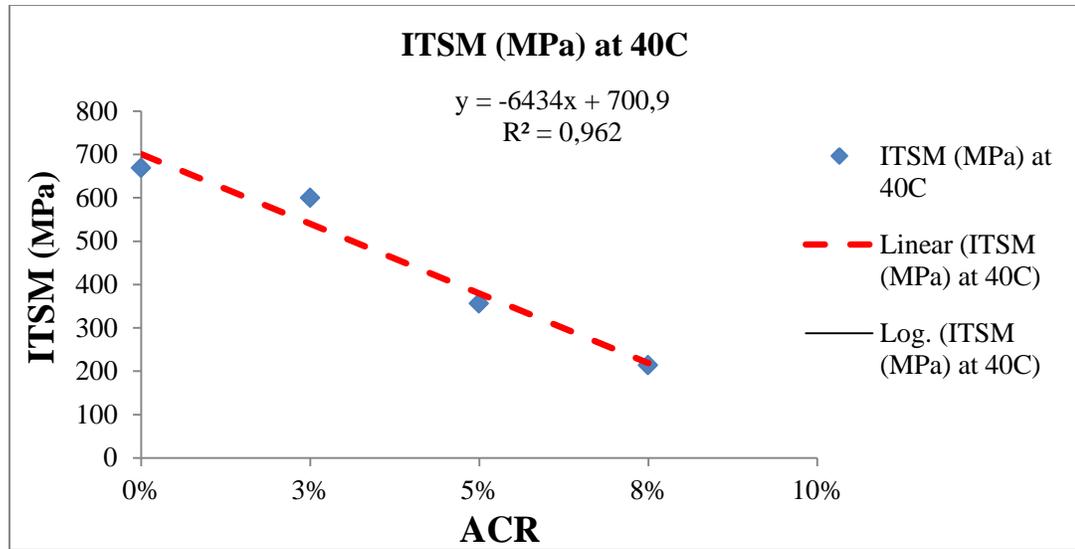


Figure 4.42. results of ITSM each and AC modified without and with CR

4.19. Permeability Test (M)

Permeability testing is important because one of the primary assumptions is structural pavement design for conventional pavement is flexible (asphalt concrete) and the pavement must be impermeable. The basis for this design approach is to minimize moisture infiltration and thus maintain adequate support from the underlying unbound materials. Table 4.16. shows the result of permeability test at OBC and Figure 4.43. and Figure 4.44. shows the summarized results for the each type of asphalt concrete at OBC.

The calculations of coefficient permeability are by the following equation:

Where diameter (D) = 2.54*4 = 10.16 cm

Height (L) = 6.127 cm

$$\text{Area (A)} = \frac{\pi \times D^2}{4} = \frac{\pi \times (10.16)^2}{4} = 79.756 \text{ cm}^2 \quad (4.3)$$

Pressure water (P) = 10Kg/cm²

Volume of water leakage (V) = 1000 ml

Time leakage 1000ml = 194 sec @ (10Kg/cm²).

$\gamma = 1 \text{ gr/cm}^2$.

$$\text{Coefficient permeability (k)} = \frac{V \times L \times \gamma}{A \times P \times T} = \frac{1000 \times 6.127 \times 1}{79.756 \times 10 \times 194} = 3.96\text{E-}07 \text{ cm/sec}$$

Table 4.16. Comparison of Permeability Test at OBC.

Crumb Rubber %	Asphalt Content	Height (L) (cm)	Area (A) (cm ²)	Pressure Water 10000 dyne/cm		Pressure Water 20000 dyne/cm	
				Time (T) sec	Permeability (K) cm/sec	Time (T) sec	Permeability (K) cm/sec
0	6.4	6.127	79.756	194	3.96E-07	60.2	6.38E-08
	6.4	6.131	79.756	207	3.71E-07	73	5.27E-08
	6.4	6.129	79.756	201	3.82E-07	75	5.12E-08
	Average				3.83E-07		5.59E-08
2.5	6.475	6.383	79.756	202	3.96E-07	61	6.56E-08
	6.475	6.41	79.756	106	7.58E-07	35	1.15E-07
	6.475	6.3965	79.756	135	5.94E-07	60.2	6.66E-08
	Average				5.83E-07		8.23E-08
5	6.45	6.408	79.756	160	5.02E-07	31	1.3E-07
	6.45	6.544	79.756	113	7.26E-07	58	7.07E-08
	6.45	6.476	79.756	143	5.68E-07	46	8.83E-08
	Average				5.99E-07		9.62E-08
7.5	6.375	6.621	79.756	81	1.02E-06	30	1.38E-07
	6.375	6.56	79.756	97	8.48E-07	32	1.29E-07
	6.375	6.5905	79.756	92	8.98E-07	35	1.18E-07
	Average				9.24E-07		1.28E-07

This relationship between the Permeability of the asphalt concrete AC and asphalt concrete modified with crumb rubber is shown in figure 4.43. And figure 4.44.

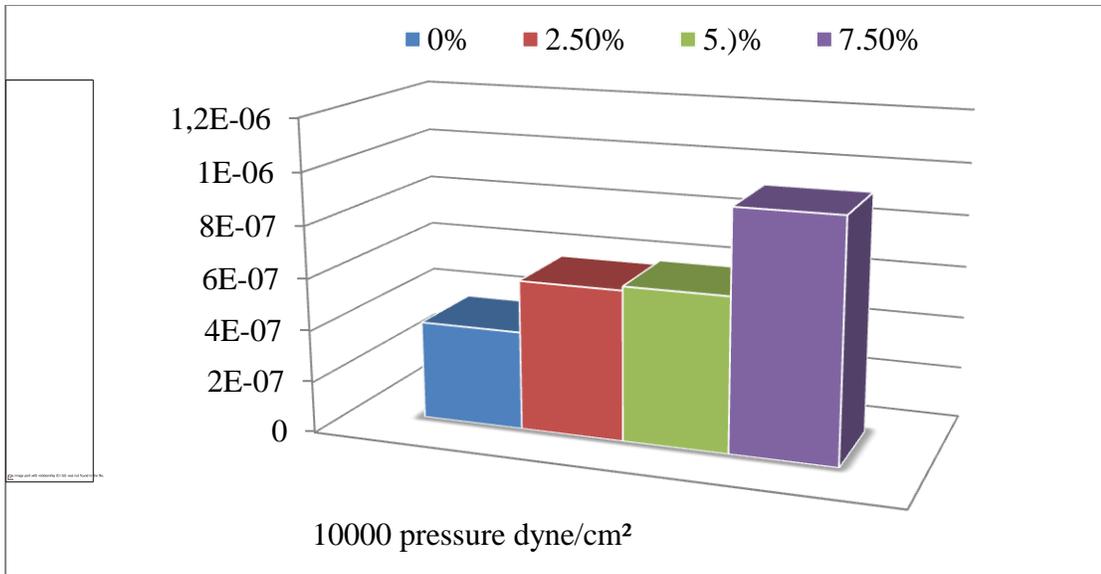


Figure 4.43. The results of permeability test at 10000 dyen/cm²

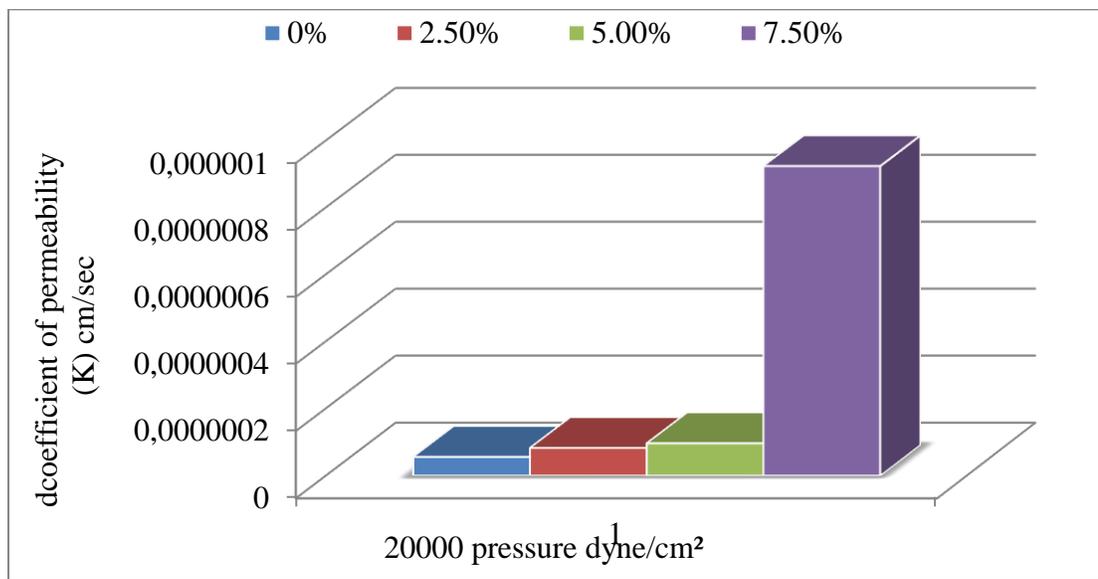


Figure 4.44. The results of permeability test at 20000 dyen/cm²

Through the review of the permeability test results in Table 4.16 and Figure 4.41 and 4.42. The following observations were obtained that the coefficient of permeability (K) value of AC with crumb rubber 7.5% is higher than asphalt concrete without crumb rubber (original) and with crumb rubber 2.5% and 5.0% by $9.24E-07$ dyen/cm² at water pressure 10000 dyen/cm² and by $9.257E-06$ dyen/cm² at water pressure 20000 dyen/cm²

The results of permeability test shows that asphalt concrete without crumb rubber is lower than AC with crumb rubber since the mixture has the lowest coefficient of permeability the higher quality. It was happened because when water leaks into the soil layer (base course), causing deformities cracks and holes observed.

The relationship between the coefficient of permeability and water pressure become an inverse relationship, because the increase of water pressure leads to a decrease in Permeability coefficient.

4.20. Summary

This study covered all the processes from primarily stages of design up to the analysis of the data obtained.

1. The stability value of asphalt concrete 60/70 pen mixture without CRM is higher than asphalt concrete with 2.5%, 5.0%, 7.5% CRM by 11.64%, 5.04% and 5%, respectively. The cohesion and the bonding ability of modified bitumen increase, when increasing the proportion of rubber.
2. The flow value of asphalt concrete without CRM is lower than asphalt concrete with 2.5%,5.0%, and 7.5%. Since the penetration value of CR modified asphaltis higher than asphalt concrete without CRM. The flow value of AC with CRM is higher as comparison with AC without CRM. Therefore, the presence of CRM in the mixture increases its flow value. The addition of more CRM contents increased the flow to an optimum level and with further addition of CRM in the mix. Higher flow values may be related to the increase of air voids by using more CRM in the mixture, which leads to a more flexible mixture.
3. Density of the Compacted Mix (CDM).

The result obtained indicated that binder content influences the compaction characteristics of the AC mixtures, thus having a significant effect on the mix density, for any specific binder content, for any binder content, the density decreased as the crumb rubber is increased in the AC mixtures. The increase in CRM content implies an increase of the bitumen absorbed by the CRM causing more voids space with the aggregate particles therefore a reduction in mix density. The reason for the

varying densities of the mixtures is because of the viscosity effect on the compatibility of the mixtures.

The increase in viscosity could be a result of the amount of asphalt in the bitumen which improves the viscous flow of the modified bitumen sample during the interaction process. The higher viscosity of the resulting binder provided better resistance during compaction of the mixture, thus resulting in lower density of the modified mix. This is in concurrence with previous finding, which revealed that for ideal paving mixture a good correlation between binder viscosity and the compaction effort is required (Altamzwi, 2011).

4. Voids in the Mix (VIM).

The durability of bituminous pavement is a function of the voids of the mix (VIM) or porosity. In general, the lower the porosity, the less permeable the mixture will be and vice versa. Too much voids in the mix (high porosity) will provide passageways through the mix for the entrance of damaging air and water. Too low porosity could lead to flushing where the excess bitumen squeezes out of the mix to the surface. The effect of the CRM content for different binder contents on the porosity of the virgin mixture and AC mixture for any binder content used, the increase in CRM content in the mixture is followed by an increase in the VIM, which is due to the contact point between the aggregates which is lower when the CRM is content increased. The high amount of crumb rubber particle absorbs the binder which is required to encapsulate the aggregate and subsequently fill the voids between aggregates.

High porosity in the bituminous mixture means that there are many voids providing passageways for the entry of damaging air and water through the mix. On the other hand, with low porosity, water flush occurs whereby bitumen is squeezed.

However, the results from concerning on the influence of bitumen show that any increase in the bitumen content of the mix leads to a decrease in the VIM value, which occurs due to the excessive bitumen filling up the air pocket between aggregates. It is therefore very important to produce a mix low enough in void to be

impermeable and hence durable, but with sufficient voids to prevent bitumen deformation.

5. The optimum bitumen content at asphalt 60/70 pen is 6.4%. While the OBC for asphalt with 2.5%, 5.0%, and 7.5% crumb rubber are 6.383%, 6.45% and 6.375%, respectively. There is no difference in the optimum bitumen content between the four types of asphalt concrete without and with CR, because it has been the same gradation of aggregates for the production of mixtures.
6. The ITS value of asphalt concrete without CR is higher than asphalt concrete with 2.5%, 5.0%, and 7.5% CR with different temperatures. Through the study of the relationship between the value of ITS test and temperature changes, it was found that normal asphalt concrete without CR is lower sensitive to heat than asphalt concrete with CR.

There is a lot of filler composition of the asphalt concrete so it can fill cavities in the asphalt concrete mix aggregate and asphalt that surrounds thicker than using asphalt without CR. The asphalt concrete with CR is less sensitive to temperature changes by using ITS test compared with asphalt concrete without CR.

7. The coefficient of permeability value of asphalt concrete without CR is lower than asphalt concrete with 2.5% CR and AC with 2.5% CR is higher than AC with 5.0% CR and AC with 5.0% CR is higher than AC with 7.5% CR at water pressure 10000 dyne/cm² and water pressure 20000 dyne/cm², and this confirmed to the result of the test density and the percentage of VITM, where find that the mixtures are practically impermeable.

From this limited assessment, it was concluded that asphalt concrete with 2.5%, 5.0%, and 7.5% crumb rubber is not suitable to be used at hot and arid region using dry process.