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Evaluation of Job-Mix Formula Tolerances as Related to Asphalt Mixtures Properties

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ABSTRACT

The current Iraqi standard specifications for roads and bridges allowed the prepared Job-Mix Formula for asphalt mixtures to witness some tolerances with regard to the following: coarse aggregate gradation by ± 6.0 %, fine aggregate gradation by ± 4.0 %, filler gradation by ± 2.0 %, asphalt cement content by ± 0.3 % and mixing temperature by ± 15 ^{o}C. The objective of this work is to evaluate the behavior of asphalt mixtures prepared by different aggregates gradations (12.5 mm nominal maximum size) that fabricated by several asphalt contents (40-50 grade) and various mixing temperature. All the tolerances specified in the specifications are taken into account, furthermore, the zones beyond these tolerances are also observed. The evaluation process is illustrated by volumetric properties such as density, air voids, voids in mineral aggregate and voids filled with asphalt. Marshall test is carried out to find stability and flow values. The resistance to moisture effect is investigated by conducting the compressive test for dry and water immersed conditions to find the index of retained strength. The experimental results supported the recommendations to increase tolerances of coarse and fine aggregate gradations to ± 7.0 % and ± 5.0 % respectively. The optimum asphalt content tolerance can be increased to ± 0.5 %. The tolerances of filler gradation and mixing temperature are preferable to keep their current values.

Key words: Asphalt, Job-Mix, tolerance, Marshall test, compressive test.

تقييم التغاير لمعادلة المزج بالنسبة لخواص الخلطات الاسفلتية

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الخلاصة

تسمح المواصفات القياسية العراقية الحالية للطرق والجسور لمعادلة المزج المعدة للخلطات الاسفلتية ان تشهد بعض التغاير بالنسبة للاتي: تدرج الركام الخشن ±6.0%, تدرج الركام الناعم ±4.0%, تدرج الحشوة ±2.0%, محتوى السمنت الاسفلتي ±0.3% وحرارة المزج ±15^{o}C . الهدف من هذا العمل هو تقييم تصرف الخلطات الاسفلتية المعدة بتدرجات مختلفة للركام (12.5مم مقاس اسمي اقصى) والمصنعة بمحتويات اسفلت متعددة (درجة 40-50) وبحرارة مزج متعددة. تم اخذ جميع التغاير المحدد بالمواصفة بنظر الاعتبار. توضح عملية التقييم بالخواص الحجمية كالكثافة, الفراغات الهوائية, فراغات الركام والفراغات المملوءة بالأسفلت. تم

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اجراء فحص مارشال لإيجاد قيم الثبوتية والزحف. تم التحقق من تأثير مقاومة الرطوبة بأجراء فحص الانضغاط للحالة الجافة والمغمورة بالماء لإيجاد معامل القوة المتبقية. النتائج العملية أسندت التوصيات بزيادة التغاير للركام الخشن والناعم الى ±7.0% و±5.0% على التوالي. من الممكن زيادة تغاير محتوى الاسفلت الامثل الى ±0.5%. من المفضل ان يحتفظ تغاير الحشوة وحرارة المزج بقيمهم الحالية.

1. INTRODUCTION

In the world of asphalt paving construction, the Job-Mix-Formula represents the cornerstone for any project. Basically, it is composed of the key elements such as the asphalt binder grade and optimum content, aggregate skeleton parameters like the maximum size and the preferable gradation. However, the determination of these values is achieved by experimental process which is subjected to the typical laboratory conditions. Unfortunately, the application of the lab design formula in the field suffer from the lack of optimum conditions, consequently it is quite normal to witness some deviations around the extreme specifications limits. For this reason, all the paving agencies permit some tolerances existence in the work accomplished by the contractor. The Iraqi standard specifications for roads and bridges, **SCRB R/9, 2003**, allowed the prepared Job-Mix Formula for asphalt mixtures to witness some tolerances with regard to the following properties: coarse aggregate gradation; fine aggregate gradation; filler content; asphalt cement content and mixing temperature. These values are listed in **Table 1**.

1.1 Objective of the Study

The objective of the work presented by this paper is to evaluate the behavior of asphalt mixtures prepared by different aggregates gradations that fabricated by several asphalt contents and various mixing temperature. All the tolerances specified in the Iraqi standard specifications are taken into account, furthermore, the zones beyond these tolerances are also observed. The evaluation process is illustrated by volumetric properties such as density, air voids, voids in mineral aggregate and voids filled with asphalt. The Marshall test is carried out to find stability and flow values. The resistance to moisture effect is demonstrated by conducting the compressive test of dry and water immersed conditions to find the index of retained strength.

2. REVIEW OF LITERATURES

After conducting a surveying for many standards published by global transportation agencies, a comparison with the specification of Iraqi standard can be made as demonstrated by the following paragraphs.

One of the most reliable specifications in the paving engineering are published by the American Society for Testing and Materials (ASTM), in their sophisticated specifications designated by **D-3515, 2014**, they declared the tolerance for the Job-Mix Formula as can be found in **Table 2**. By observing this table, it is interesting to note that the ASTM criterion divided the coarse aggregate to two categories, one of them is established for aggregate size that is greater than 12.50 mm with high tolerance value of ± 8.0 %, the other category is occupied by aggregate size ranged between 9.50 mm and 4.75 mm with a tolerance value equal to ± 7.0 %. This trend is also occurred in the situation of fine aggregate, herein, the fine aggregate is divided to two parts, the first one specified for aggregate size between 2.36 mm and 1.18 mm with tolerance value equal to ± 6.0 %, the other part is addressed for aggregate size ranging from 600 µm to 300 µm with ± 5.0 % tolerance value. As regard to the mineral filler tolerance, this value is specified by ± 3.0 %. This specification allowed high tolerance value for the optimum asphalt content which is equal to ± 0.5 %.

The main conclusion that is resulted from comparing the ASTM specification for the tolerance values with the Iraqi specification for the same subject, is that all the value founded in the ASTM criteria are higher than the Iraqi limits.

The world widely known document of British standard which are comply with the European standard demonstrate the tolerances of preparing asphaltic mixture through the published document **BS EN 13108-21, 2005**, that is shown in **Table 3**. By examine the information in this table, it is obviously shown that British-European Standard allowed higher tolerance values as compared with the ASTM specification, an interesting point of discussion is that asphalt content variation in this specification is free to move by two times as compared with the Iraqi standard.

The standard that come much close to the Iraqi standard when talking about the tolerance in asphalt mixture ingredients is the Australian Standard that declared by **Document No. 71/06/101, 2011**, and listed in **Table 4**, the tolerance for asphalt content is identical with the Iraqi standard as ± 0.3 %, the other components enclosed between ± 7.0 % for coarse aggregate and ± 1.5 % for mineral filler. Another specification that is similar to Iraqi specification regarding to the same subject of tolerances is the Texas specifications, **FHWA, 2009**, announced by department of transportation which can be found in **Table 5**. The similarity in these limits criterion includes filler and asphalt contents as ± 2.0 % and ± 0.3 % respectively.

Colorado department of transportation, **FHWA, 2009**, reported the specification limits for asphalt mixture components tolerance values through their speciation which gathered in **Table 6**, herein, also there is some similarity with the Iraqi specification especially with the filler percentage.

The variations in the amounts of course, fine and mineral filler defiantly affected the performance of asphalt concrete mixtures. In this way, **Roberts, et al., 1996**, emphasized that aggregate gradation is the most important property which almost controls all other performance parameters of asphalt mixtures including stability, durability and stiffness. **Chen and Liao, 2002**, depicted that replacement of some portion of coarse aggregate particles by natural fine type will dramatically higher the level of plastic deformation for paving mixtures. A research conducted by **Kim, et al., 2009**, revealed that prepared mixture with aggregate gradation band above the line of maximum density exhibit the highest density and flow parameters while the lower gradation band witness the lowest values. **Golalipoura, et al., 2012**, reported that best rutting resistance attained when the gradation of aggregate pass above the middle region in the contrary to the lower region which shoes the worst resistance ability.

3. MATERIALS AND METHODS OF TESTING

3.1 Asphalt Mixtures Composition

This paper practically focused the sight into the properties of wearing course pavement. The following materials were utilized in preparing the asphalt mixtures:

- 40-50 penetration grade of asphalt cement obtained from Al-Daurah refinery,
- 12.5 mm nominal aggregate maximum size brought from Al-Nibaee quarry,
- Natural sand and limestone dust brought from Karbala province.

Initially, all the asphalt mixtures components (binder and aggregates) have been subjected to all necessary tests that justify their use. In this regard, penetration, kinematic viscosity, softening point, ductility, flash point and specific gravity tests were performed on asphalt cement, the gained results are presented in **Table 7**. Furthermore, bulk and apparent specific gravity, water absorption and percent of wear tests were employed to characterize the aggregate properties, the output of these tests are listed in **Table 8** and **Table 9.**

The preparation of specimens consists of sieving the aggregate to the desired sizes and recombined with the mineral filler to satisfy the specifications requirements as listed in **Table 10** and plotted in **Fig.1**. Following this phase, the desired weight of asphalt binder was heated to the temperature that produce a kinematic viscosity of 170 ± 20 centistokes (*i.e.* 150 ^oC) and mixed thoroughly with preheated aggregate within two minutes. To complete the molding process, the compaction procedure conducted at temperature that produce an asphalt binder kinematic viscosity of 280 ± 30 centistokes (*i.e.* 140 ^oC). Marshall test and compressive test were conducted to furnish all the necessary data to accomplish the purposes of this work.

3.2 Resistance to Plastic Flow (Marshall Test Method)

This method covers the measurement of the resistance to plastic flow of cylindrical specimens (101.6 mm in diameter and 63.5 mm in height) of bituminous paving mixtures loaded on the lateral surface by means of Marshall apparatus according to **ASTM D-6927, 2014**. This test was utilized for all formed mixtures. Besides, it has been conducted on specimens mixed with different values of asphalt binder to determine the optimum asphalt content which was designated as the value that obeys the following criteria:

- Maximum stability and density values,
- Flow value range from 2.0 mm to 4.0 mm,
- Air voids value range from 3.0 % to 5.0 %,
- Voids in mineral aggregate, 14.0 % as a minimum value, and
- Voids filled with asphalt value range from 70.0 % to 85.0 %.

The bulk specific gravity test, **ASTM D-2726, 2014**, and theoretical (maximum) specific gravity test, **ASTM D-2041, 2014**, were founded for each specimen. The percent of air voids in total mix was then calculated according to the following formula:

$$\% \text{ Air Voids} = [\, 1 - \text{Bulk sp.gr.} / \text{Max. Theo. sp.gr.}] \times 100 \qquad (1)$$

3.3 Index of Retained Strength Test

To practically evaluate the harmful action of moisture presence on the compressive strength of asphaltic mixtures, a numerical index of reduced compressive strength is obtained by comparing the compressive strength of standard conditioned mixtures with the compressive strength of mixtures that have been immersed in water as prescribed by the following formula:

$$\text{Index of Retained Strength (IRS), \%} = (S_2 / S_1) \times 100 \qquad (2)$$

where:

S_1 = compressive strength of dry specimens,
S_2 = compressive strength of immersed specimens.

For each aimed mixture variable, six cylindrical specimens (101.6 mm in diameter and 101.6 mm in height) were made following the procedure described in **ASTM D-1074, 2014**. One set of three specimens was tested in dry condition by storing in air bath for 4 hours at 25±1^oC before applying an axial load at a rate of 5.08 mm/min and the failure load was recorded as **S_1**. The other specimens were immersed in water path for 24 hours at 60 ^oC and were transferred to another water path at 25 ^oC for 2 hours to bring the specimens to the test temperature before applying the same load rate and the failing load was recorded as **S_2**. The Iraqi specification specify the Index of Retained Strength to be 70 % as a minimum value.

4. RESULTS AND DISCUSSION

Initially, performing Marshall test for different specimens mixed with various asphalt contents revealed the optimum content value for wearing course pavement to be 4.70 % by weight of total mix. All the results related to this determination are visualized in **Fig.2.**

The specimens fabricated by incorporating the optimum asphalt content are employed as a control mixture of zero tolerances for coarse aggregate, fine aggregates, mineral filler, asphalt content and mixing temperature. The results of Marshall properties and index of retained strength are utilized according to the requirements of Iraqi specifications. The control mixture yields Marshall properties as follows: 13.0 kN for stability, 3.05 mm for flow, 2.354 gm/cm^3 for density, 3.62 % for air voids, 14.98 % for voids in mineral aggregate and 75.8 % for voids filled with asphalt. The index of retained strength for control mixture was 75 %. Basically, all the Iraqi specifications requirements which listed in SCRB R/9 were satisfied for the control mixture.

Fig.3 and **Fig.4** explain graphically the results which have been obtained by conducting Marshall test with the variation of coarse aggregate gradation by positive and negative tolerances. Visual inspection to these figures revealed that significant change occurred for stability and air voids values while other parameters witness relatively small changes. Lower values of Marshall stability occurred as the tolerances increased incrementally on the both sides of zero tolerance, in other words, gradation with tolerance of +8.0 % reduce the stability by 36.92 % and the air voids by 10.93 % while the -8.0 % tolerance reduced the stability by 21.84 % and increased the air voids by 36.66 %. Nevertheless, the resulted parameters still obey the requirements of Iraqi specifications, whereas, the minimum value of Marshall stability equals 8.2 kN.

Fig.5 depicts the influence of positive fine aggregate gradation on Marshall properties, as can be seen, increasing the tolerance significantly changed the stability and the flow values, elevating the tolerance value to 6.0 % reduced the stability by 15.07 % and increased the flow by 25.90 %.

The effect of negative tolerance of fine aggregate gradation on Marshall properties is show in **Fig.6**, herein, for the same tolerance of 6.0 %, the stability dropped by 16.46 % while the flow and air voids increased by 35.08 % and 22.86 % respectively. Fortunately, none of the designated parameters exceeded the limits of the specifications.

The behavior of asphalt mixtures when the amount of mineral filler is increased can be illustrated visually in **Fig.7**. It can be deduced that increasing the filler content to some extent enhanced the mixtures stability, after a while, some reduction occurred. The marked change observed for air voids content, whereas, increasing filler by 4.0 % tolerance reduced the air voids by 15.79 %.

The effect of negative tolerance of filler content is shown in **Fig.8**. The dramatically change in Marshall properties was recorded when the filler content decreased by an incremental change of 1.0 %. Stability value decreased by 42.0 % as the tolerance continues to elevate till reached 4.0 %. For the same tolerance increment, the flow value also suffers from huge amount of increasing till reach 78.68 % causing this parameter to exceed the specification limit. Furthermore, reducing the filler content to the maximum designated tolerance caused the air voids content to be increased by 44.94 % which exceed the specification limit in this regard. However, when the tolerance was -3.0 %, the resulted parameters remained in the acceptable zone.

The effect of asphalt cement tolerance is postulated in **Fig.9**. It is clearly shown that all the Marshall properties maintained their acceptable values even that stability value decreased by 21.53 % when the tolerance increased to 0.6 % and the air voids increased by 24.24 % for -0.6 % tolerance.

Fig.10 demonstrated the variation in Marshall properties as the mixing temperature moved above and under the control mixture standard mixing temperature (*i.e.* 150 ^{o}C). An essential conclusion can be drawn from visual inspection of this figure, that is, wherever mixing temperature elevated or lowered, the Marshall properties witness a remarkable decline in their desired values, especially for stability, flow and air voids. The higher temperature possesses the worst situation, as the temperature increased by 30 ^{o}C, the stability decreased by 36.53 % and the flow increased by 82.29 %. Although the temperature clearly affects the resulted properties, yet, they still remained in the acceptable region expect for flow value.

Figs.11 to **15** plotted the relationships between tolerances of asphalt mixture components as stated in the Iraq specifications (coarse aggregate, fine aggregate, mineral filler, asphalt cement content and mixing temperature) and the index of retained strength that obtained by performing compressive strength test for dried and water immersed specimens.

Fig.11 depicts the effect of coarse aggregate gradation on ITS, it can be noticed that slight reduction occurred as the tolerance increased, however, this parameter became 68 % when the tolerance increased positively to 8.0 % and became 66 % as the tolerance negatively increased by the same magnitude.

Fig.12 illustrated the influence of fine aggregate tolerance on ITS, by observing this figure, it is clearly shown that fine aggregate gradation changing is not affecting the resulted ITS excluding the situation of -6.0 %, in this case, the ITS slightly reduced to be 68 %.

The effect of filler content tolerance on ITS is shown in **Fig.13**, herein, the only point of conflict with the specification limits occurred at -4.0 % tolerance as the ITS reduced to 68 %.

Fig.14 postulated the variation in ITS values as the optimum asphalt content increased and decreased by specified increments. A better result of ITS are gained (78 %) when the asphalt content was increased by 0.6 %. On the contrary, reducing asphalt content caused a reduction in ITS values, in this way, a 71 % of ITS value was obtained for mixture fabricated by asphalt content lower than optimum value by -0.6 %.

The effect of mixing temperature on ITS value is shown in **Fig.15**. In this case, increasing mixing temperature by 30^{o}C (180 ^{o}C) reduced the value of ITS to 66 % which is less than the specified limit of 70 %, following the same path, decreasing the mixing temperature by 30 ^{o}C (120 ^{o}C) also lowered the ITS value to 68 %.

5. CONCLUSIONS

- Preparing asphalt mixtures with maximum coarse aggregate gradation tolerance maintained the acceptable limits of Iraqi specifications regarding Marshall properties. For index of retained strength value, some reduction of the recommended limit was occurred. Marshall stability dropped to 8.20 kN and 10.16 kN for +8.0 % and -8.0 % tolerances respectively. It could be possible to extend the tolerance limit from ± 6.0 % to ± 7.0 %.
- The impact of fine aggregate tolerance witnesses the least effect, Marshall stability become 11.04 kN and 10.86 kN for +6.0 % and -6.0 % tolerances respectively. All other volumetric properties remained within approved values. The only problem occurred when the index of retained strength became 68 % as the fine aggregate tolerance increased to -6.0 %. Depending on the evaluation process, the fine aggregate tolerance might be increased from ± 4.0 % to ± 5.0 %.

- Reducing the filler content of the optimum value by 4.0 % caused a significant reduction in the mixture properties as Marshall stability declined to 7.54 kN while increasing this value by same amount slightly decreased the corresponding Marshall stability to 12.45 kN. The current work recommended to keep the existing filler tolerance as ± 2.0 %.
- Changing asphalt contents within ± 0.6 % around the optimum value, keep all the resulted properties in the acceptable area of the specifications. Marshall stability became 10.20 kN and 11.30 kN when the maximum tolerance of 0.6 % value was used. The index of retained strength recorded higher value of 78 % as the asphalt content increased by 0.6 %. This work recommended to increase the tolerance of asphalt cement content to ± 0.5 % instead of ± 0.3 %.
- Although, the properties of asphalt mixtures hold their desired values as the mixing temperature increased or decreased more than the specified tolerance of ± 15 ^{o}C, it is preferable to keep the mixing temperature below than 165 ^{o}C and higher than 135 ^{o}C to avoid aging effect and asphalt mix temperature dropping during transportation to the site of paving.

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NOMENCLATURE

ASTM	american Society for Testing and Materials
BS	british Standard
EN	european Standard
FHWA	federal Highway Administration
IRS	index of Retained Strength

S_1	compressive strength of dry specimens,
S_2	compressive strength of immersed specimens.
SCRB	the State Corporation for Roads and Bridges
sp.gr.	specific gravity
VFA	voids filled with asphalt
VMA	voids in mineral aggregate

Table 1. Tolerances from Job-Mix Formula according to the SCRB-R/9,2003 standard.

Property	**Tolerance**
Aggregate passing sieve 4.75 mm (No.4) or larger	± 6.0 %
Aggregate passing sieve 2.36 mm (No.8) to 0.3 mm (No.50)	± 4.0 %
Filler passing sieve 0.075 mm (No.200)	± 2.0 %
Asphalt content	± 0.3 %
Mixing Temperature	± 15 ^{o}C

Table 2. Tolerances from Job-Mix Formula according to the ASTM standard (D-3515,2014).

Sieve Size	**Tolerances, %**
12.5 mm and larger	± 8
9.5 mm and 4.75 mm (No.4)	± 7
2.36 mm (No.8) and 1.18 mm (No.16)	± 6
600 µm (No.30) and 300 µm (No.50)	± 5
75 µm (No.200)	± 3
Bitumen content, weight % of total mixture	± 0.5

Table 3. Tolerances from Job-Mix Formula according to the European standard (BS EN 13108-21,2005).

Sieve Size (mm)	**Tolerances**
31.5	-9 +5
20	± 9
6.3	± 9
2.0	± 7
0.250	± 5
0.063	± 3
Binder Content	± 0.6

Table 4. Tolerances from Job-Mix Formula according to the Australian standard (Document No. 71/06/101,2011).

Particle Size Distribution AS Sieve Size (mm)	Tolerances on Percentage by Mass Passing
4.75 and larger	± 7
2.36 and 1.18	± 5
0.6 and 0.3	± 4
0.150	± 2.5
0.075	± 1.5
Bitumen content, weight % of total mixture	± 0.3

Table 5. Tolerances from Job-Mix Formula according to the Texas DOT standard.

Description	Allowable Difference from JMF Target
Individual % retained for #8 sieve and larger	± 5.0
Individual % retained for sieves smaller than #8 and larger than #200	± 3.0
Percentage passing the #200 sieve	± 2.0
Asphalt content, %	± 0.3

Table 6. Tolerances from Job-Mix Formula according to the Colorado DOT standard.

Property	Maximum Tolerance for any one sample
3/4" (19 mm)	± 7.0
1/2" (12.5 mm)	± 7.0
#4 (4.75 mm)	± 6.0
#8 (2.36 mm)	± 6.0
#50 (0.3 mm)	± 4.0
#200 (0.07 mm)	± 2.0
Asphalt content, %	± 0.4

Table 7. Physical properties of Al-Daurah 40-50 asphalt cement**.**

Test	Unit	ASTM Designation No.	Result	SCRB, R/9 Requirements
Penetration @ (25 ^oC, 100 gm, 5sec)	1/10 mm	D-5	48	40-50
Softening Point (Ring & Ball)	(^oC)	D-36	52	……
Specific Gravity @ 25 ^oC	……	D-70	1.03	……
Ductility @ (25 ^oC, 5 cm/min)	cm	D-113	> 100	>100
Flash Point, (Cleveland Open Cup)	(^oC)	D-92	319	> 232

Table 8. Physical properties of Al-Nibaee aggregate**.**

Property	ASTM Designation No.	Coarse Aggregate	Fine Aggregate
Bulk Specific Gravity	C-127 & C-128	2.600	2.640
Apparent Specific Gravity	C-127 & C-128	2.644	2.652
Percent of Water Absorption	C-127 & C-128	0.435	0.562
Percent of Wear (Los Angeles Abrasion Test)	C-131	19.69	……

Table 9. Physical properties of limestone dust.

Property	Result
% Passing Sieve No.200	100
Specific Gravity	2.87

Table 10. The gradation of combined aggregate for wearing course (Type IIIA) (maximum Size, 19 mm).

Sieve Size	Specification Range, (%)*	Work Limit, (%)
3/4"	100	100
1/2"	90-100	95
3/8"	76-90	83
No.4	44-74	59
No.8	28-58	43
No.50	5-21	13
No.200	4-10	7

***(SCRB R/9, 2003)**

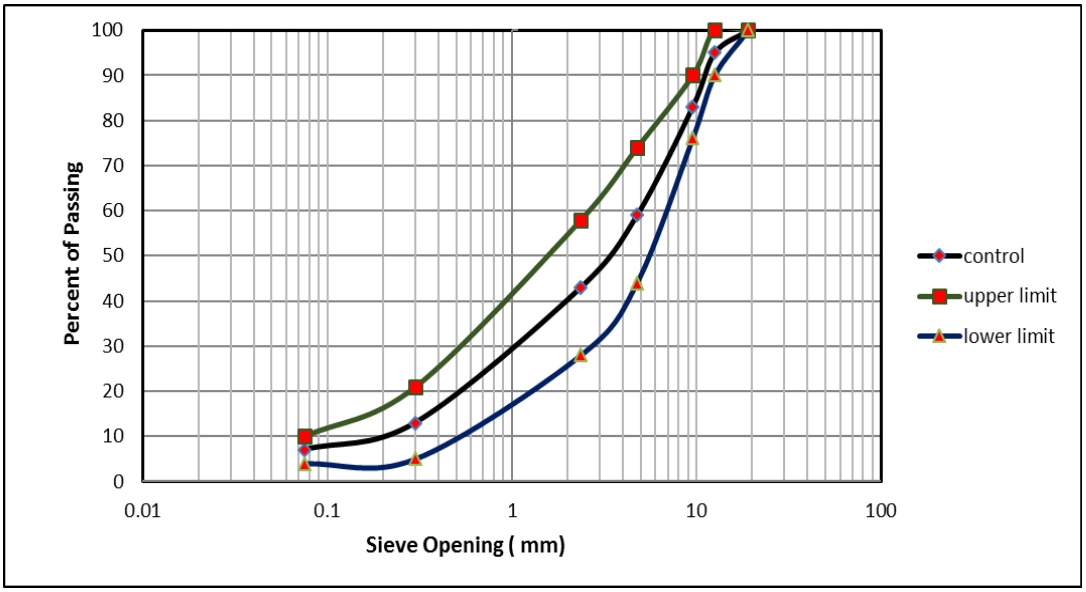
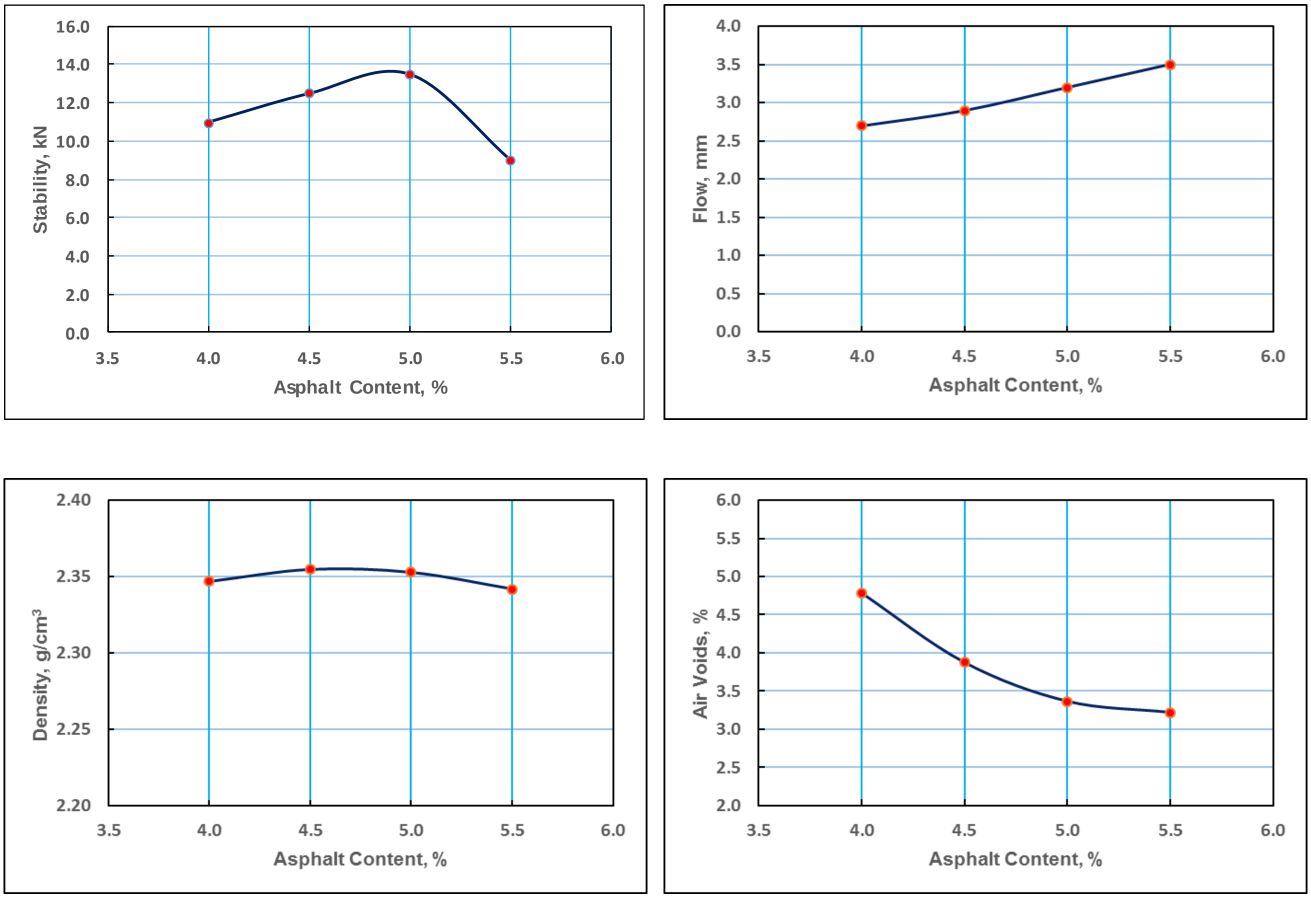


Figure 1. Gradation of combined aggregate for wearing course.



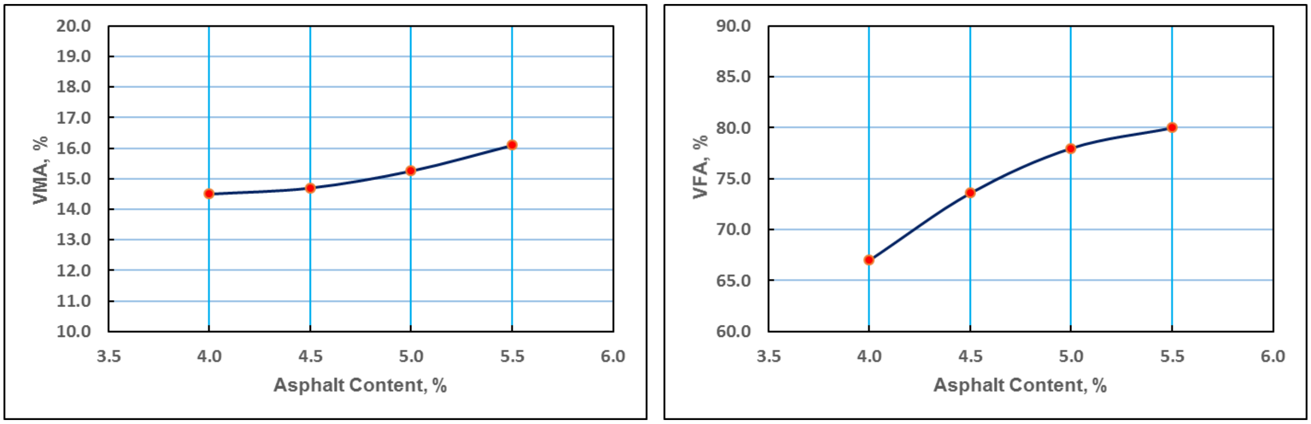
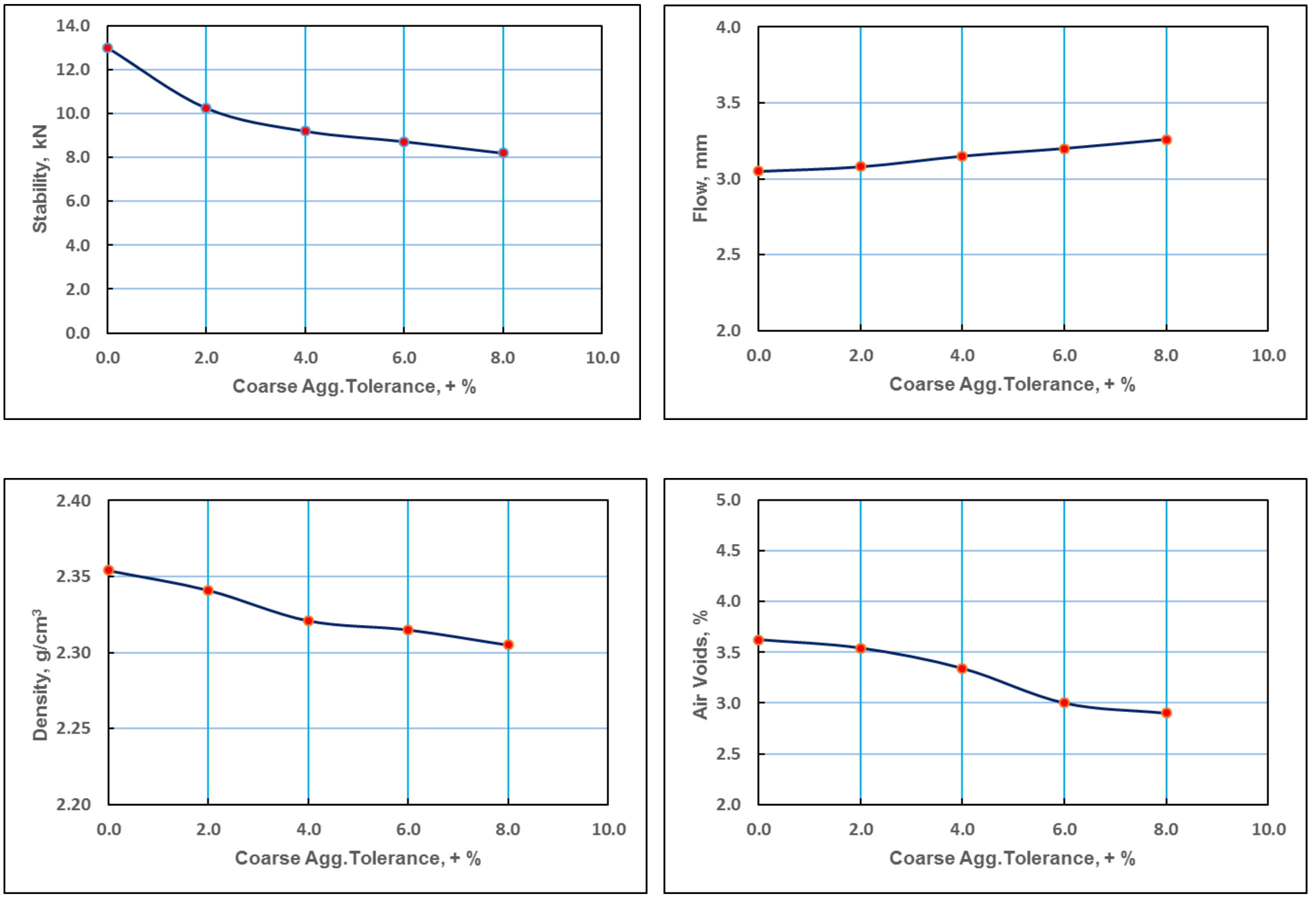


Figure 2. Determination the optimum asphalt content for wearing course pavement.



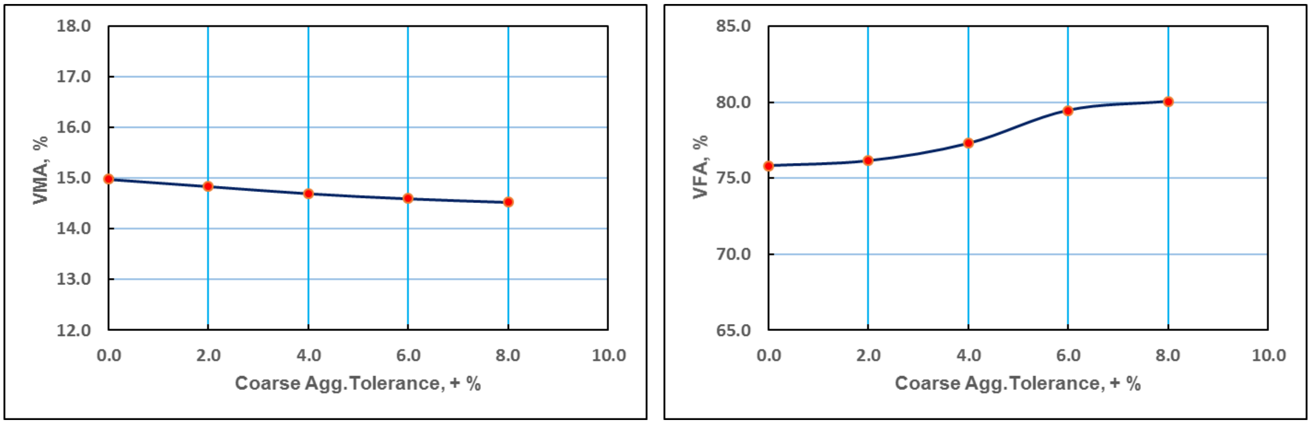
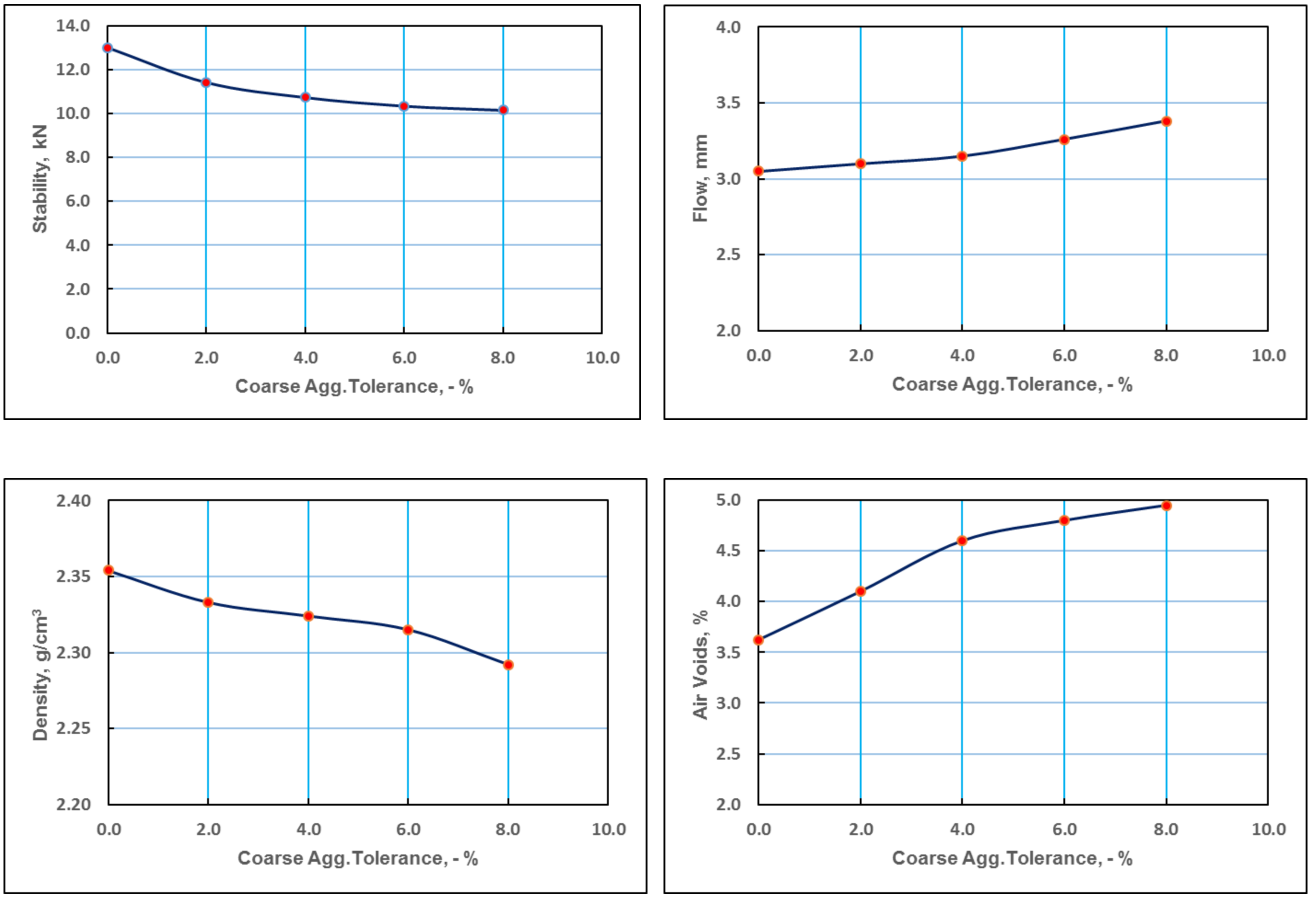


Figure 3. Effect of positive coarse aggregate tolerance on Marshall properties.



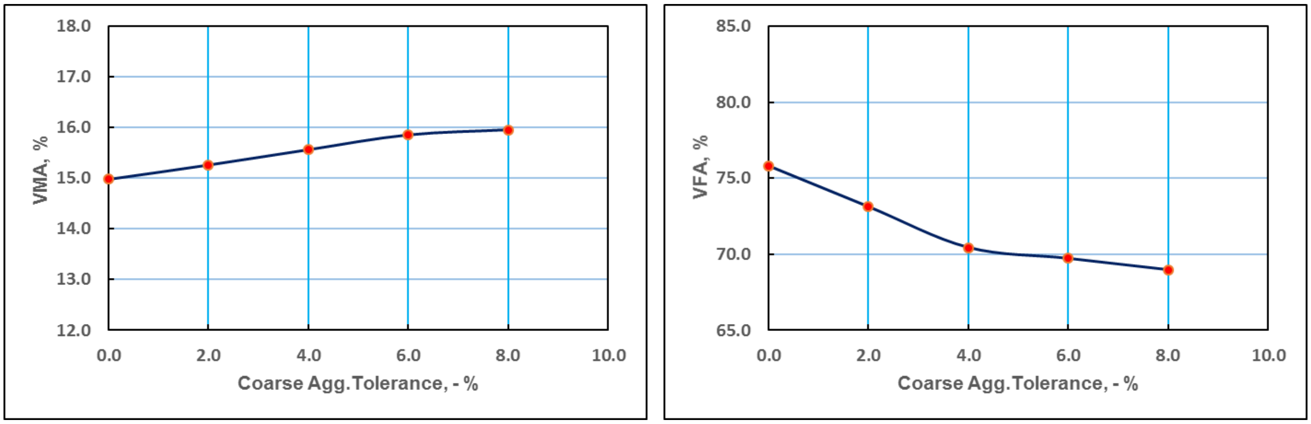
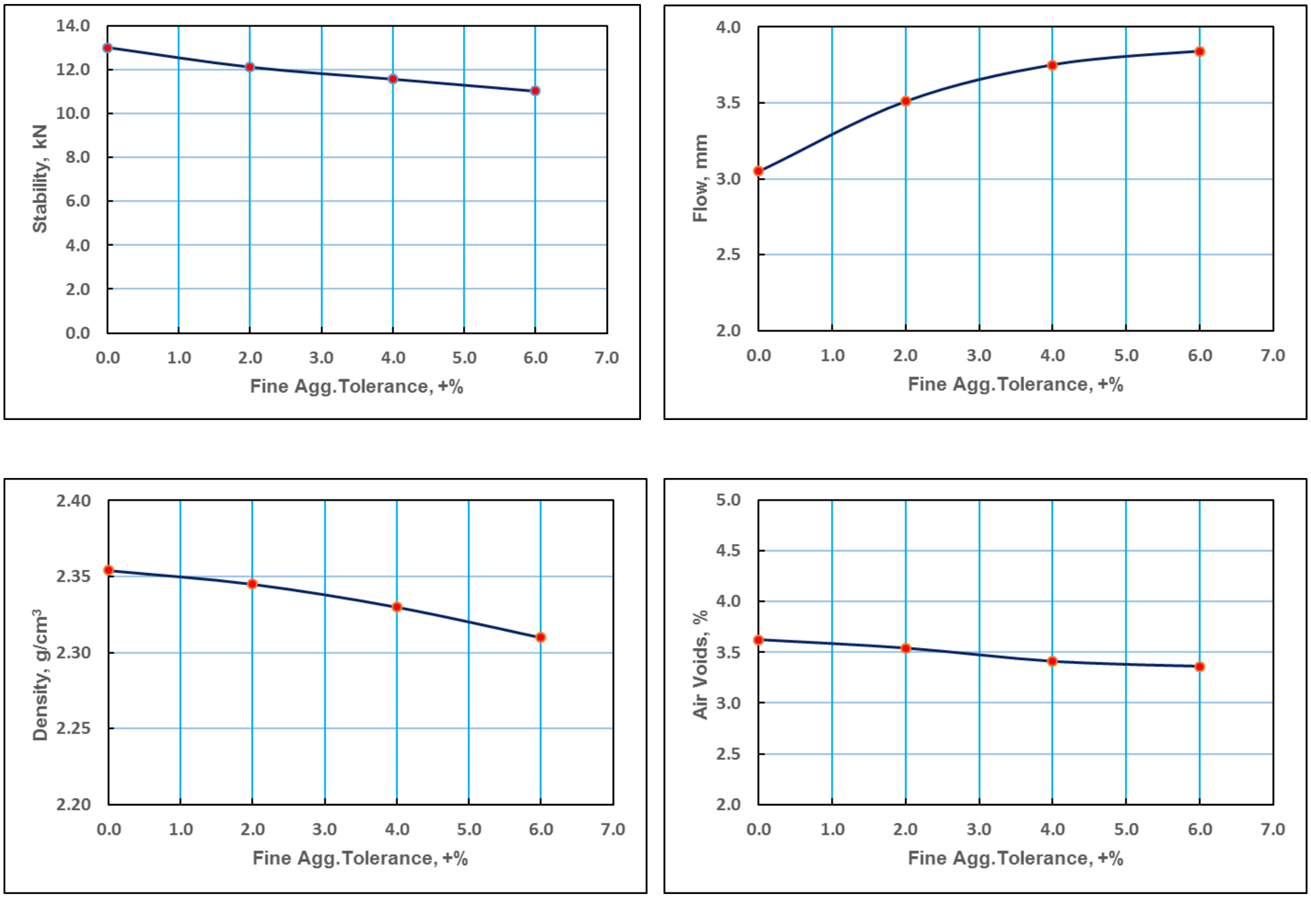


Figure 4. Effect of negative coarse aggregate tolerance on Marshall properties.



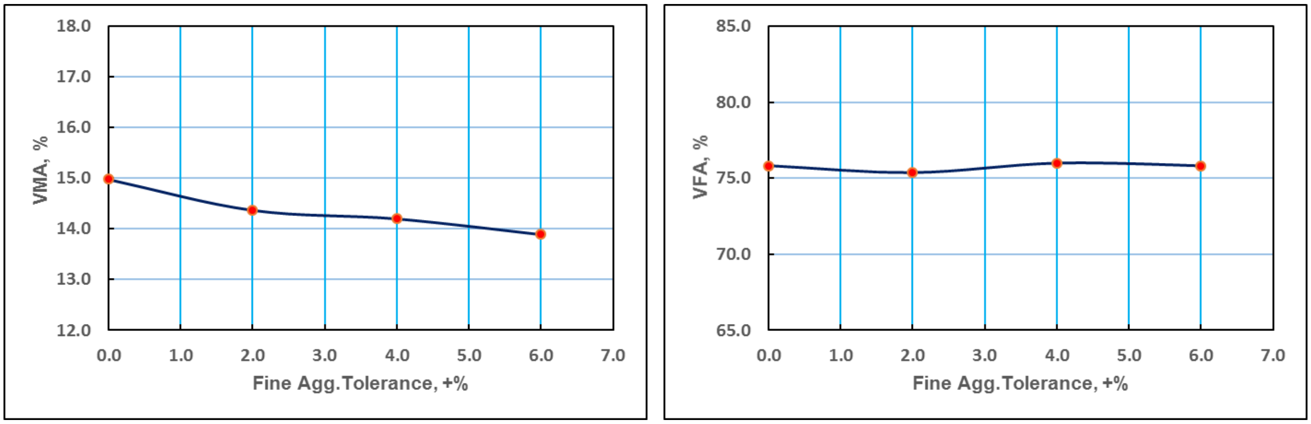
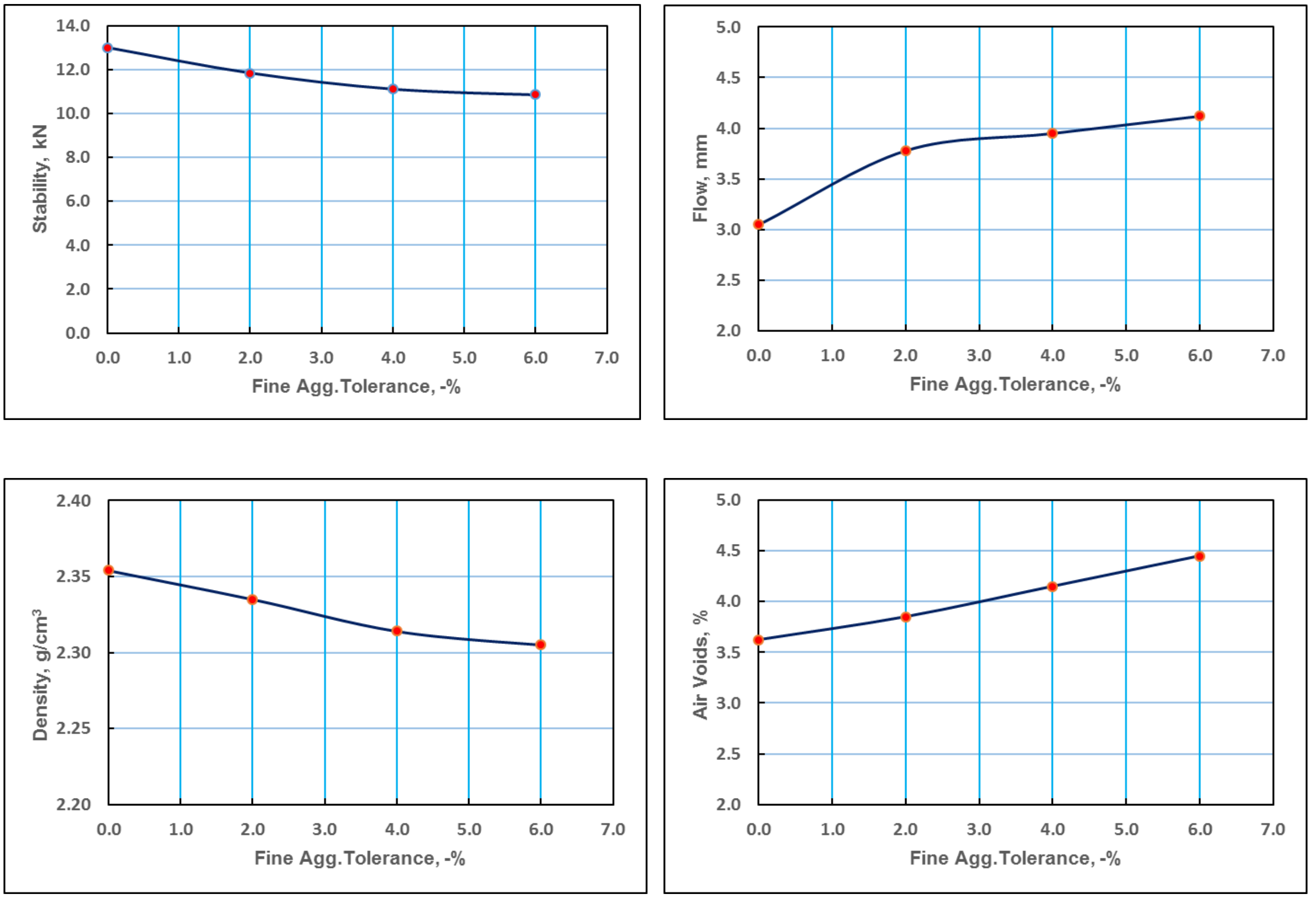


Figure 5. Effect of positive fine aggregate tolerance on Marshall properties.



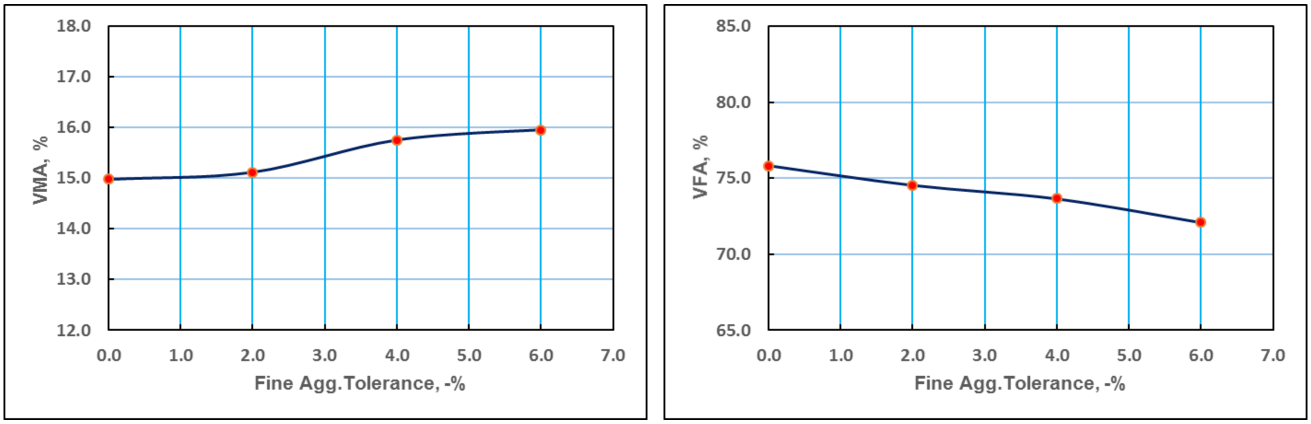
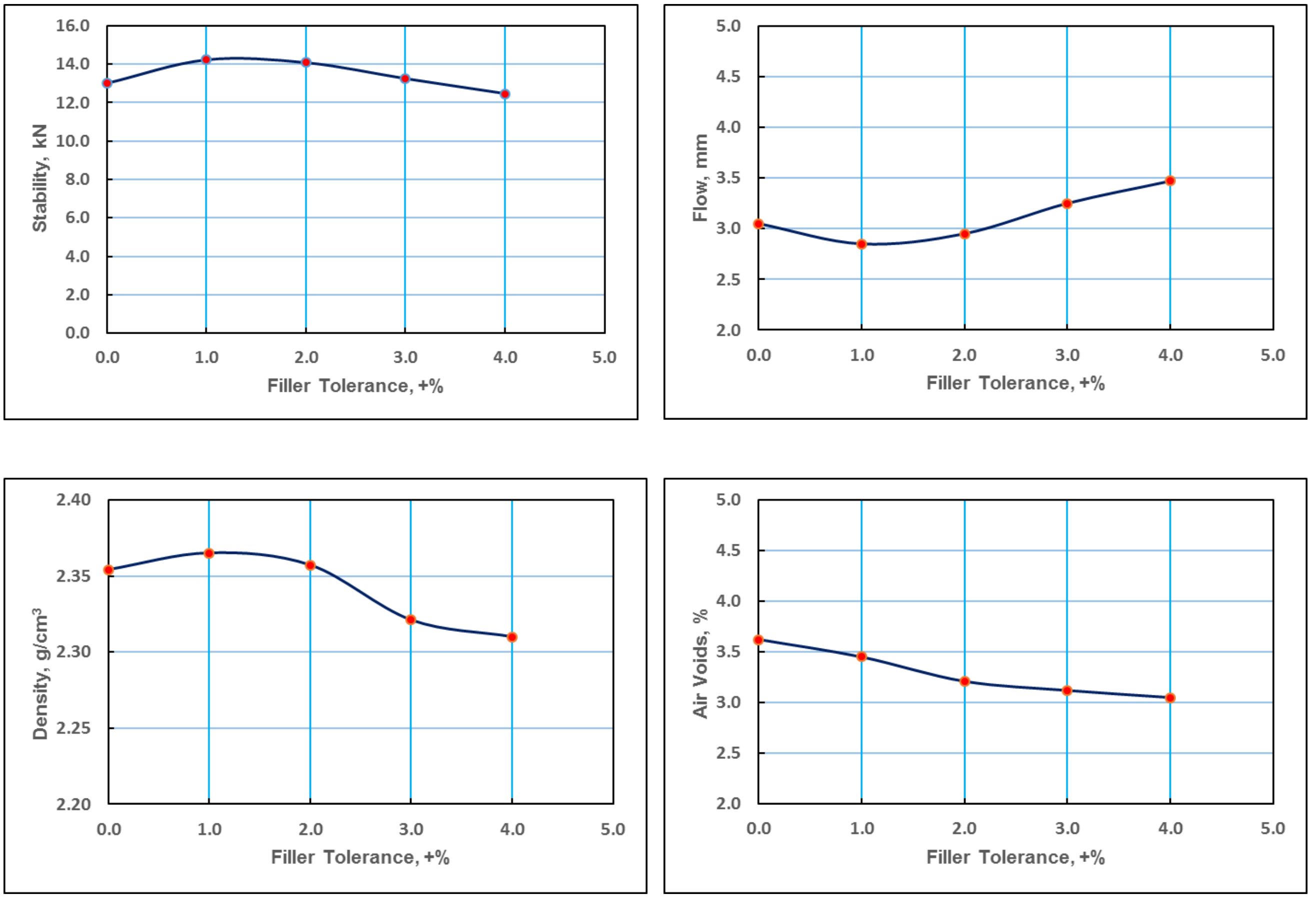


Figure 6. Effect of negative fine aggregate tolerance on Marshall properties.



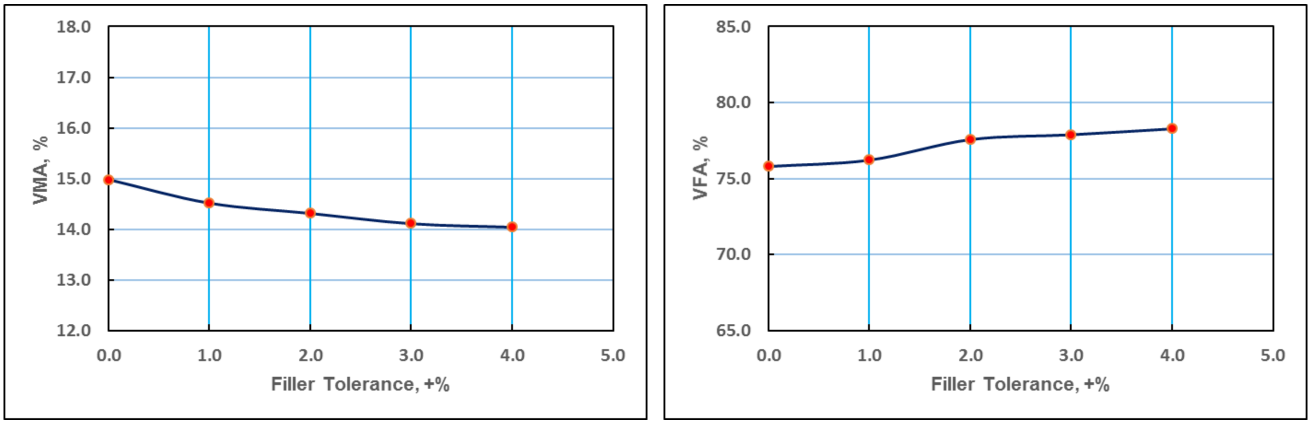
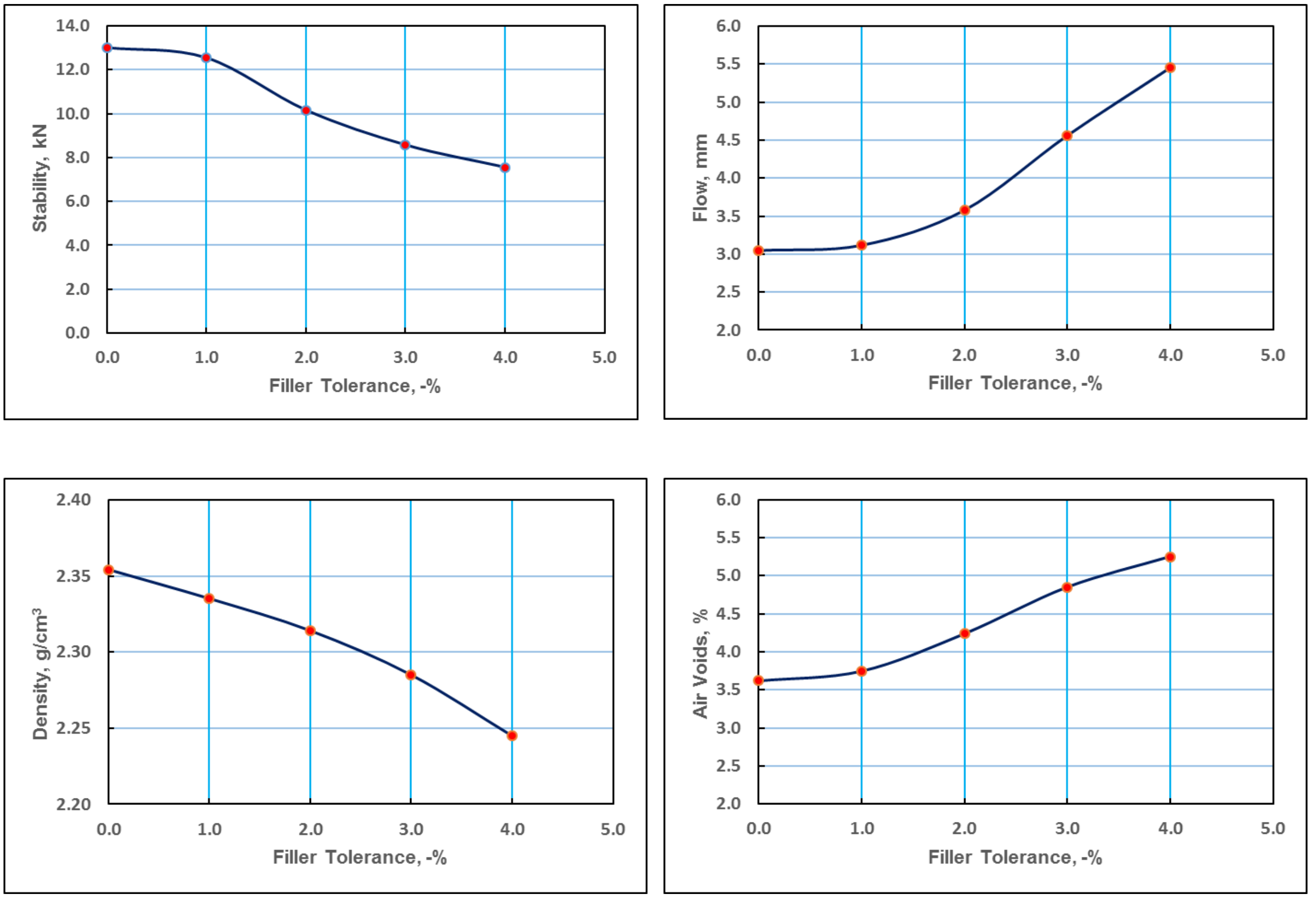


Figure 7. Effect of positive filler tolerance on Marshall properties.



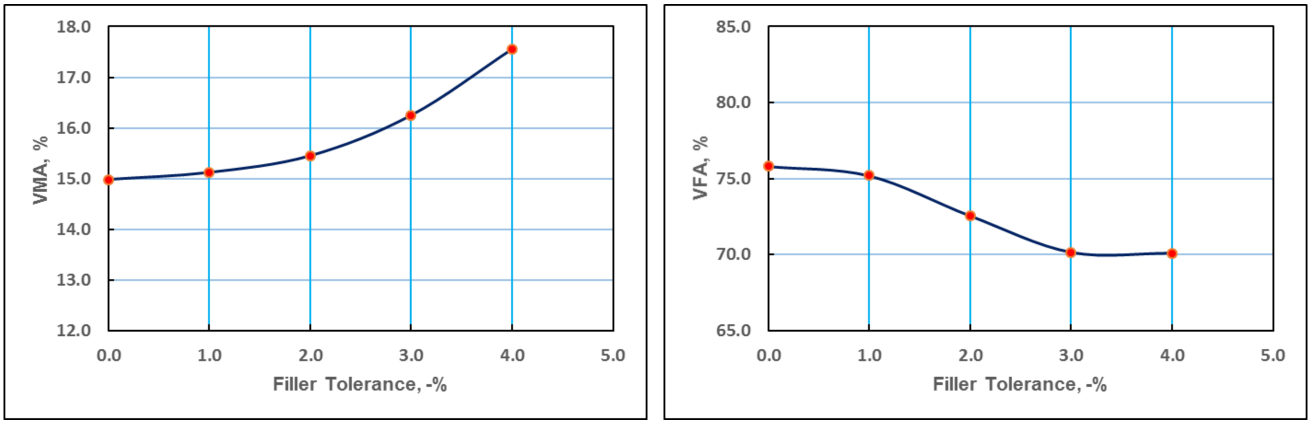
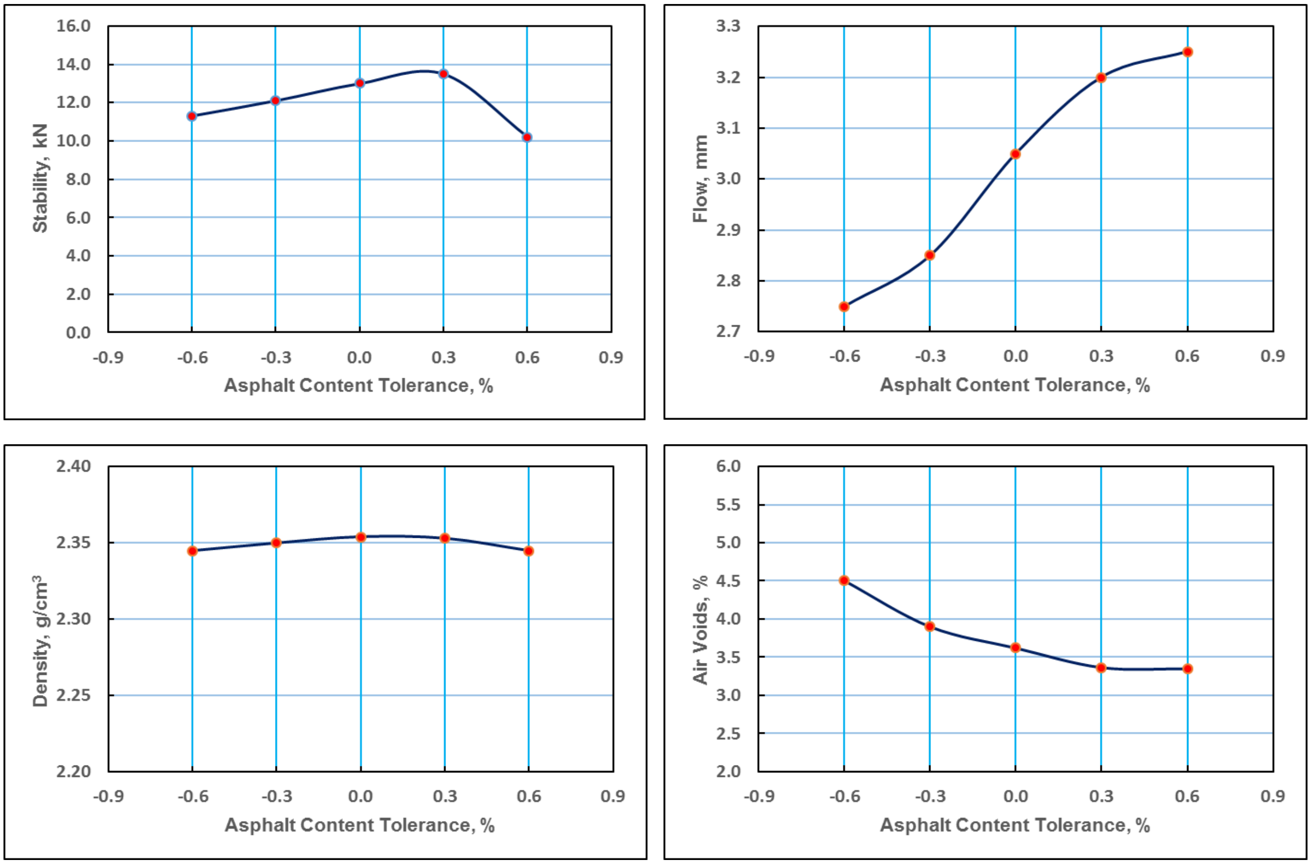


Figure 8. Effect of negative filler tolerance on Marshall properties.



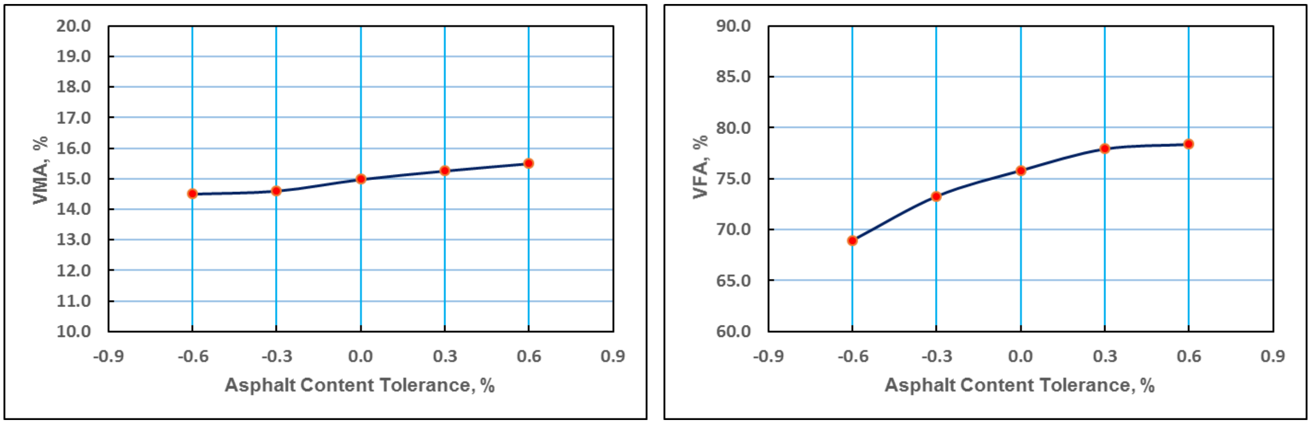
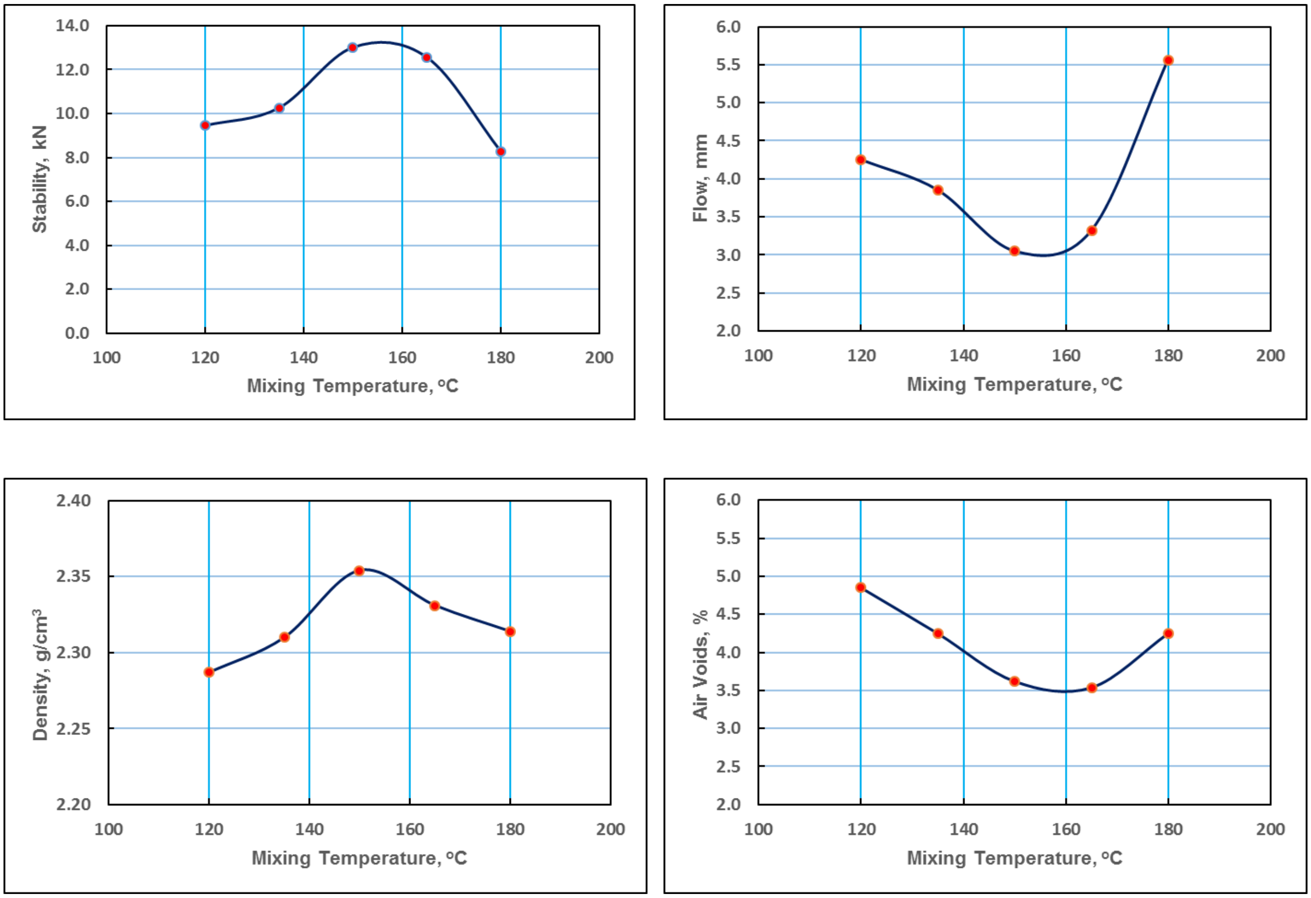


Figure 9. Effect of asphalt content tolerance on Marshall properties.



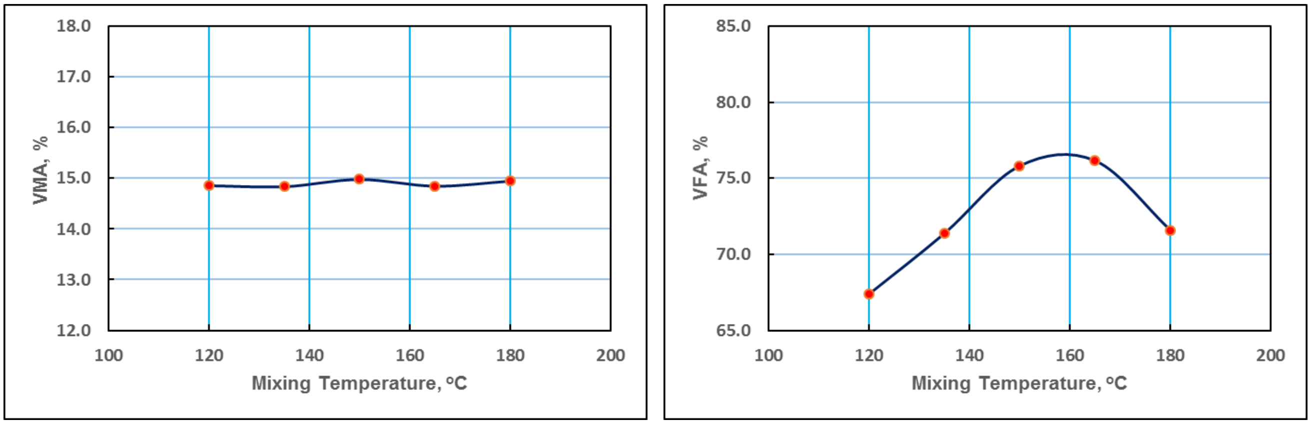


Figure 10. Effect of mixing temperature on Marshall properties

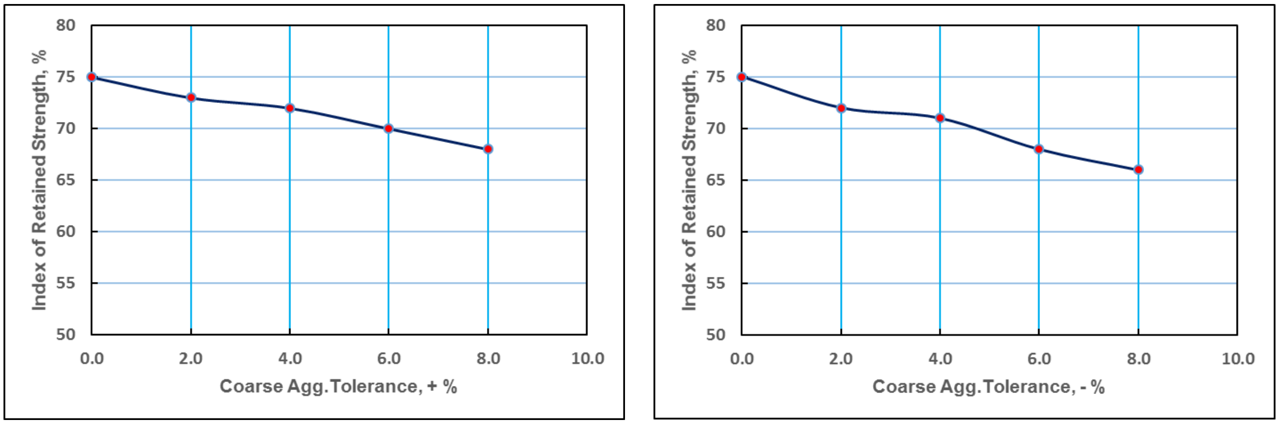


Figure 11. Effect of coarse aggregate tolerance on index of retained strength.

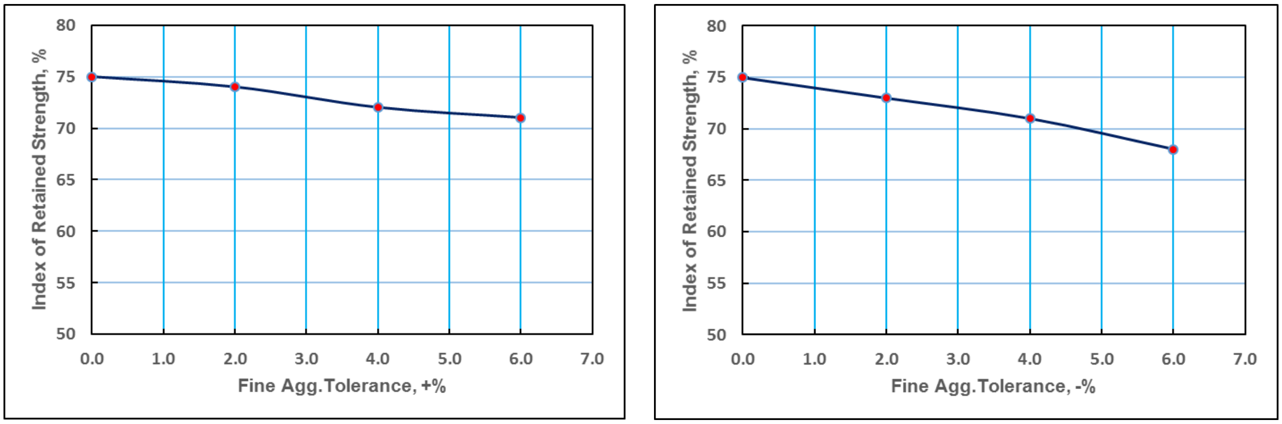


Figure 12. Effect of fine aggregate tolerance on index of retained strength.

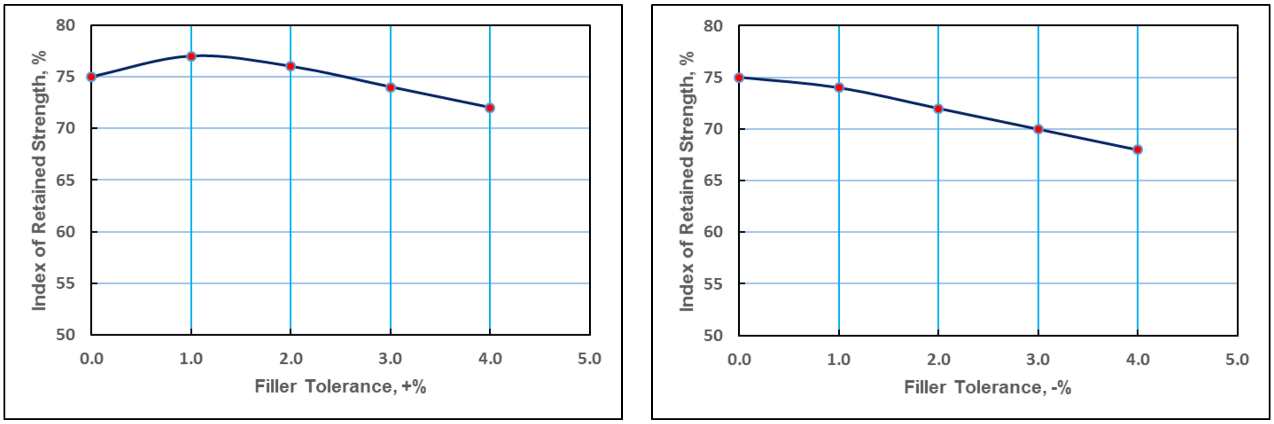
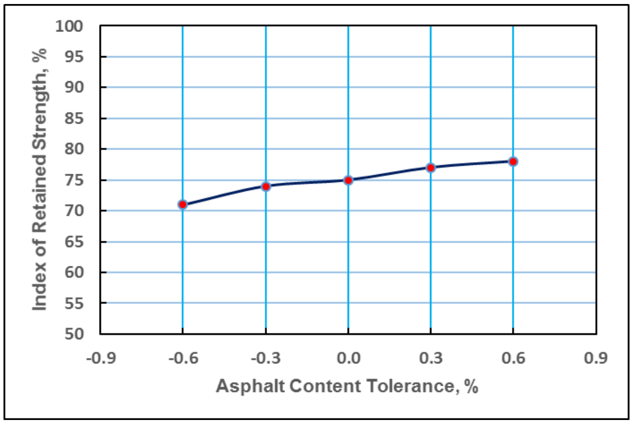


Figure 13. Effect of filler tolerance on index of retained strength.



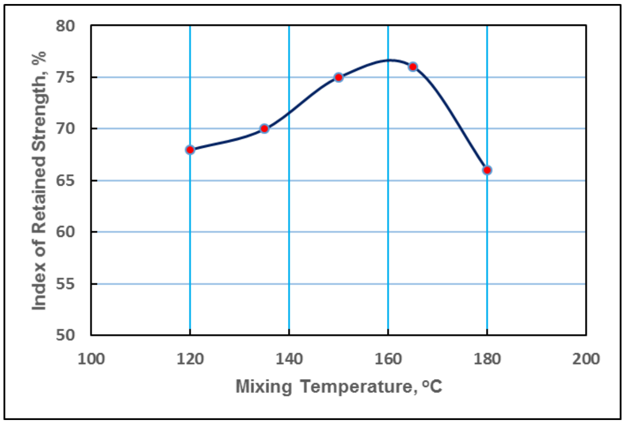


Figure 14. Effect of asphalt content tolerance on index of retained strength.

Figure 15. Effect of mixing temperature on index of retained strength.