AN INTEGRATED TOOL FOR AGGREGATE BLENDING FOR BITUMINOUS CONCRETE LAYER USING C# PROGRAMMING

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ABSTRACT: Asphalt concrete mix design is a complex process. The optimum binder content to be used is determined through Marshall Stability Test. In any given layer of the pavement, the mixture of aggregates to be used shall satisfy specific gradation. Several methods are proposed to blend the aggregates belonging to different stockpiles which include; trial and error method, optimization method etc. This discussion brings to the front the necessity of a tool for aggregate blending.

In India, the grading requirements are specified through Ministry of Road Transport and Highways (MoRTH). The density of the gradation chosen is best evaluated through 0.45 power chart in asphalt concrete mix design. The Bailey method which considers packing characteristics of the chosen aggregates is now being used widely to address the mobility and compactibility of the mix.

At present, the selection of the blend is being done using trial and error method. In this work, an attempt is made to develop an integrated tool which would guide the designers to select appropriate blend based on MoRTH recommendations, nearness to maximum density line and the Bailey parameters.

The software tool has been developed using C# Programming through Forms application to provide designers an interactive graphic user interface (GUI).

Key Words: Bituminous concrete mix design, Job Mix Formula, Gradation, Maximum density line.

1. Introduction

Bituminous concrete mix design is a complex process. Bitumen is used as binder material in the mixture to hold aggregate in place. Aggregate particles of different size are used in the mixture to make the mix dense with a specified mix volumetrics [1]. The desired level of a particular aggregate size in the mix is specified through range of percent passing by agencies local to a particular country. In India, MoRTH guidelines are being followed [2].

During the construction of flexible pavements since it is not possible to sieve in the field, aggregates are blended from different stockpile sources to achieve a desired level of gradation. Studies have shown that the pavement performance is linked to the gradation adopted [3]. Also, the issues of mobility and compactibility issues have been brought into the light by researchers [4] and to address this, Bailey method of gradation has come into practice and is now being used widely [5].

This article presents an integrated tool which was developed using C# programming. The tool will aid mix design engineers and researchers in selection of aggregate blend based on recommendations by local agencies, Bailey method and also the blend placement on 0.45 power gradation chart proposed by Fuller and Thomson [6].

2. MoRTH recommendations

In India, MoRTH [2] has issued guidelines for selection of gradation for different layers of flexible pavement. The resultant percent passing obtained by blending different aggregate stock piles is called Job Mix Formula (JMF). In Bituminous Concrete (BC) wearing course grade II, the lower and upper percent passing values have been recommended by MoRTH. Oftentimes, researchers use mid-point gradation which is obtained by taking the average of lower and upper percent passing values. The chosen JMF should fulfil the requirements of MoRTH. The recommended gradation as per MoRTH for BC Grade II is presented in Table 1. This is the first and foremost important criteria for selecting a particular blend.

Table 1 MoRTH recommendation for BC Grade II

Particle Size (mm)	19	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Lower (%)	100	79	70	53	42	34	26	18	12	4
Upper (%)	100	100	88	71	58	48	38	28	20	10

3. Fuller & Thomson Approach

Fuller & Thomson have devised a power chart in the design of concrete mix design. The percent passing for a particular size is calculated using the following expression.

$$PP = \left[\left(\frac{p}{P}\right)^n\right] * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

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Where
PP – percent passing on maximum density line
p – size of the aggregate
P – maximum size of the aggregate
n – 0.5 recommended for cement concrete mix and 0.45 for asphalt concrete

The maximum size aggregate is one sieve larger than the sieve on which at least 10% of the aggregate is retained.

For each of these proportions generated by the software, the level of gradation closer to the maximum density line is evaluated by the statistical parameter Root Mean Square Error (RMSE) [7].

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (PP_{\max.density} - PP_{JMF})_i^2}{n}} \quad \text{.....(2)}$$

Where

$PP_{max\ density}$	-	Percent Passing corresponding to the i^{th} particle for the maximum density line in the mixture
PP_{JMF}	-	Percent Passing corresponding to the i^{th} particle in the trial blend
i	-	Index for the particle in the mixture
n	-	Total number of particle sizes in the mixture

The blend of aggregates which fulfil the requirements of MoRTH and Bailey with least RMSE (closer to maximum density line) will be recommended for final implementation.

The JMF to be adopted for the asphalt mix requires that the blend should be close to the maximum density line. In the present work, this is second criteria considered for developing the blending tool.

4. Bailey Method and Parameters

Bailey Parameters will be evaluated for the percent passing of each blend obtained. The parameters will be worked out as per the following formulae.

$$CA\ Ratio = \left(\frac{PP_{Half\ Sieve} - PP_{PCS}}{100 - PP_{Half\ Sieve}} \right) \text{.....(3)}$$

$$FA_c\ Ratio = \frac{PP_{SCS}}{PP_{PCS}} \text{.....(4)}$$

$$FA_f\ Ratio = \frac{PP_{TCS}}{PP_{SCS}} \text{.....(5)}$$

CA Ratio	-	Coarse Aggregate Ratio
$PP_{half\ sieve}$	-	Percent Passing Half Sieve
PCS	-	Primary Control Sieve = 0.22 x NMPS
SCS	-	Secondary Control Sieve = 0.22 x PCS
TCS	-	Tertiary Control Sieve = 0.22 x SCS
PP_{PCS}	-	Percent Passing Primary Control Sieve
PP_{SCS}	-	Percent Passing Secondary Control Sieve
PP_{TCS}	-	Percent Passing Tertiary Control Sieve

The factor 0.22 was arrived after considering the analysis of 2-D and 3-D packing of different shaped particles. 2-D Analysis has shown the particle diameter ratio equal to 0.155 (all round) and 0.289 (all flat) with an average of 0.22 for angular and sub angular particles [8]. These parameters will be computed from percent passing of each blend generated in the process.

In the present research work, the nominal maximum particle size was chosen as 12.5mm (BC Grade II). The CA ratio between 0.50 and 0.65 and other two ratios in the range 0.35 to 0.50 [5] have been chosen, as recommended in Bailey's specifications.

(a) CA Ratio: The three ratios, discussed above, are chosen based on NMPS. It was observed that the mixtures with lower values than recommended, of CA Ratio are subjected to segregation and are generally gap-graded mixtures, while the mixtures with higher values of CA Ratio will have issues related to continuity of gradation and difficulty in compaction.

(b) FA_c Ratio: While the mixtures with lower values of FA_c ratios will have non-uniform gradation and will have problems of compaction, the higher values will indicate the presence of excessive amounts of fine aggregate leading to tender mixtures. The mixtures with higher values of FA_c ratio will show hump in the 4.75 mm region and below, when plotted on a 0.45 power gradation chart.

(c) FA_f Ratio: This ratio explains how fine aggregates pack together and influence the voids in the mixture. Typically, dense graded mixtures will have FA_f less than 0.50. Also, VMA increases with the decrease in this ratio.
This is the third and last criteria considered for blend selection in this work

5. Need for a software tool

In order to combine all the three above criteria, EXCEL spread sheet will be of limited use. Therefore it is proposed to develop a graphic user interface (GUI) based tool using C# (C-sharp). C# can provide good GUI environment for users to enter the input data in the prescribed fields, manipulates the data in the backend by generating all possible combination of blends and evaluating them for three criteria discussed above.

6. The software

The software was developed using Microsoft Visual Studio through Windows Form application module. The form will have a number of data grids, buttons and text boxes where the input and output are displayed. The input required for the JMF is the percent passing of different stock piles. Two or three coarse aggregate stockpiles, Dust and Mineral filler stock piles are usually considered for blend selection for BC Grade II. Stock piles samples are collected for quarry sites and sieve analysis will be conducted to determine the percent passing of the aggregates. The screenshots of the software while execution are presented though Fig 1 through 3 and brief explanation of them is presented through Table 2 for ready reference. The software developed can be run on system installed with Microsoft .NET version 4.5 or higher.

Table 2 Description of Screen shots

Figure No	Description
1	This window loads the default percent passing of the stock piles. On left, the cells in the top data grid can be clicked and percent passing values can be edited.
2	The window displays the aggregate blends with Bailey Ratios. Blends which have fulfilled only MoRTH will be shown in yellow colour.
3	The gradation of dust was altered to get blends fulfilling MoRTH and Bailey approach. Blends fulfilling both MoRTH and Bailey was shown in green colour. The blend with least RMS error will be selected for implementation.

Six trails were made to alter the dust to get blends fulfilling both MoRTH and Bailey. The trials made are summarised as under in Table 3. The proportion of mineral filler is kept at 2%.

Table 3 Results of Software for different dust proportions

Particle Size (mm)	Dust 1	Dust 2	Dust 3	Dust 4	Dust 5	Dust 6
	(percent passing)					
19	100	100	100	100	100	100
13.2	100	100	100	100	100	100
9.5	100	100	100	100	100	100
4.75	90	90	95	95	98	95
2.36	75	80	80	75	75	85
1.18	60	60	60	60	60	60
0.6	40	40	40	40	40	40
0.3	28	28	28	28	28	28
0.15	18	18	18	18	18	18
0.075	8	8	8	8	8	8
Passed in MoRTH	37	37	37	37	37	36
Passed in MoRTH & Bailey	0	0	0	0	0	26
CA Ratio (Min)	0.5584	0.4702	0.5631	0.6569	0.7222	0.4693
(Max)	0.6391	0.5339	0.6512	0.7679	0.8582	0.5374
FA_c	0.5532	0.5200	0.5200	0.5532	0.5532	0.4906
	0.5517	0.5194	0.5185	0.5517	0.5515	0.4899
FA_f	0.4923	0.4923	0.4923	0.4923	0.4923	0.4923
	0.4893	0.4910	0.4893	0.4893	0.4887	0.4910

Legend:

Acceptable Bailey's Ratios

Altered percent passing values for dust gradations

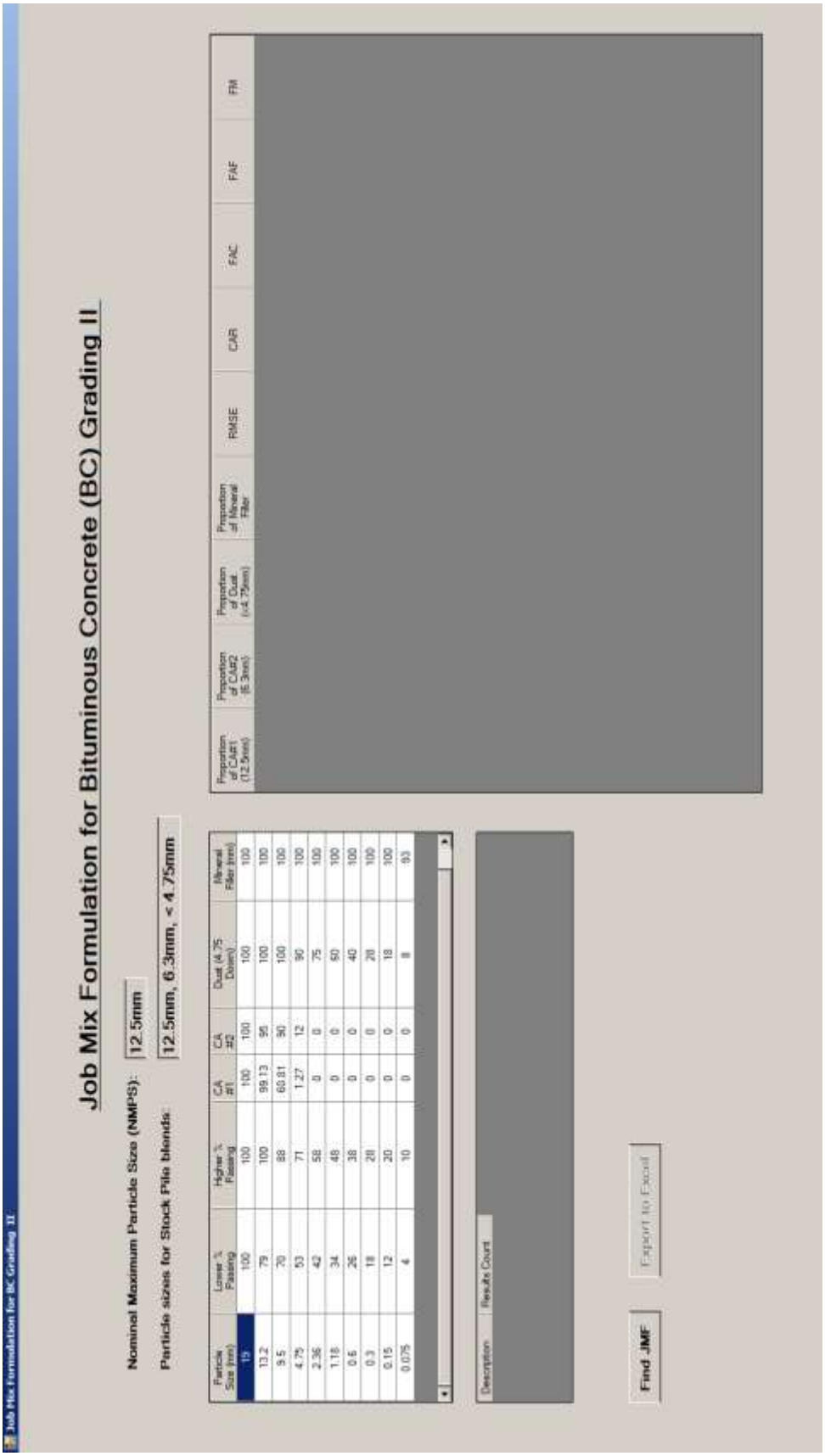


Fig 1 The screenshot before generating blends

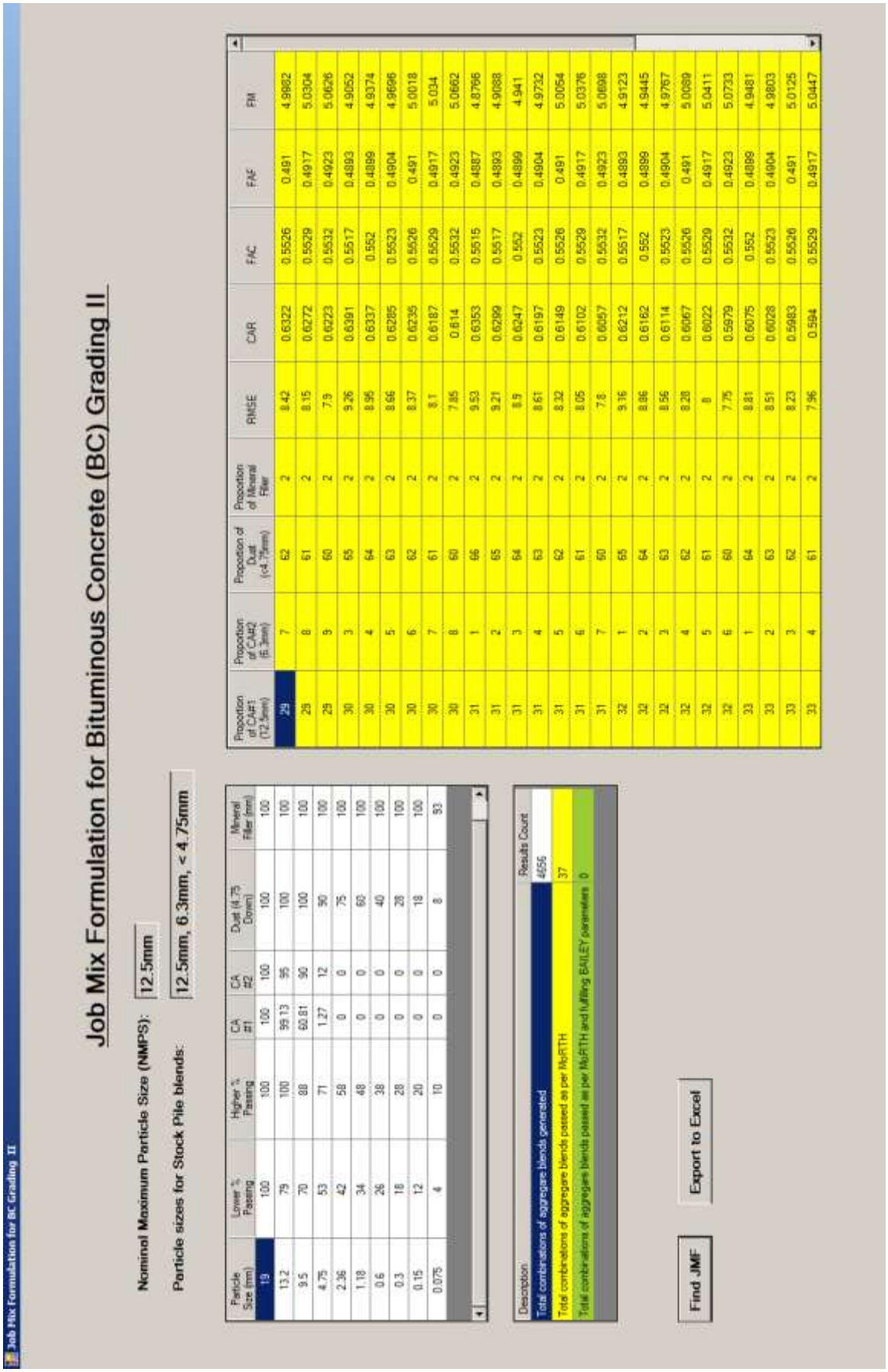
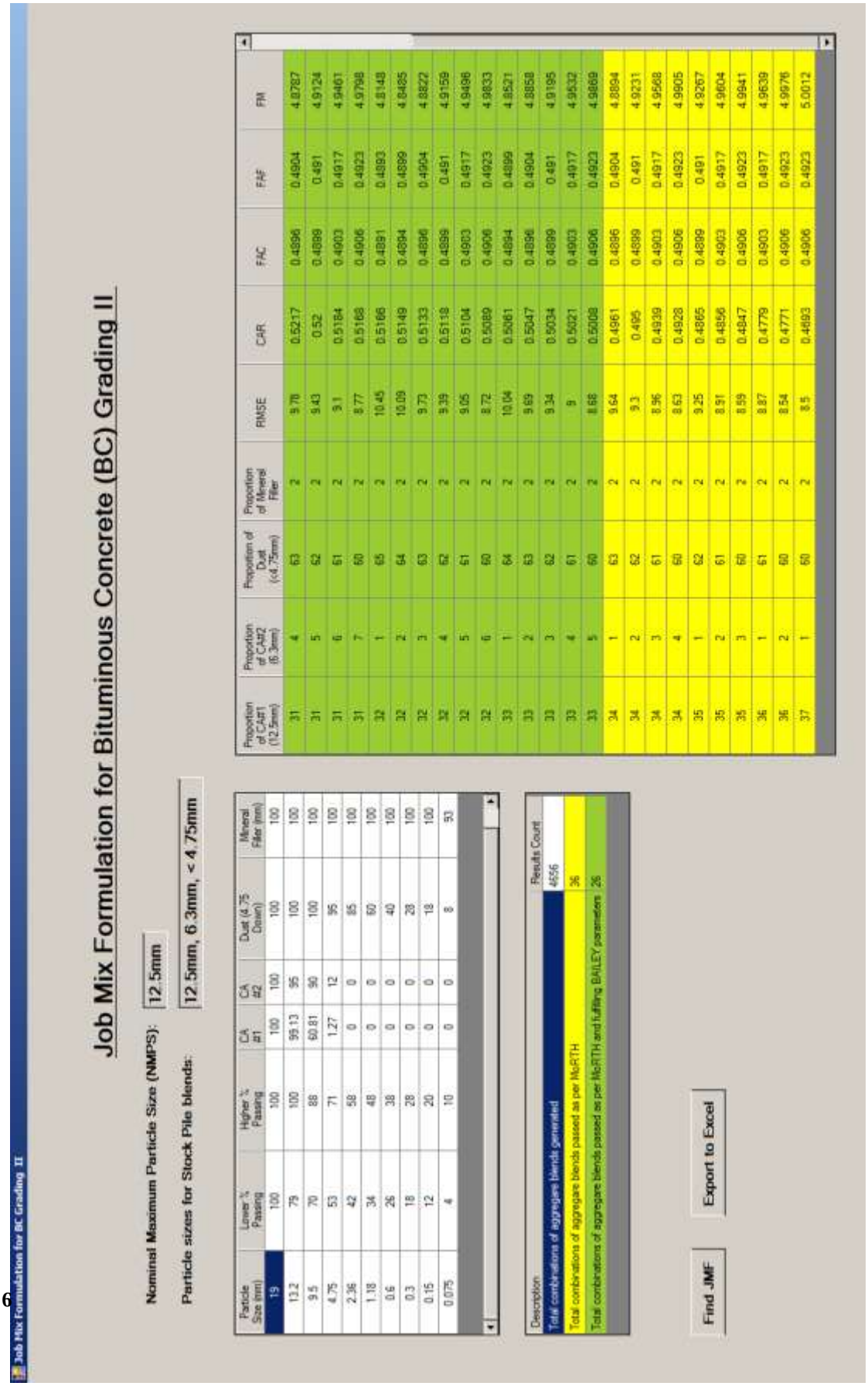


Fig 2 Screenshot after generating blends



Particle Size (mm)	Lower % Passing	Higher % Passing	CA #1	CA #2	Dust (4.75 Down)	Mineral Filler (mm)
19	100	100	100	100	100	100
13.2	79	100	99.13	95	100	100
9.5	70	88	80.81	90	100	100
4.75	53	71	1.27	12	95	100
2.36	42	58	0	0	85	100
1.18	34	48	0	0	60	100
0.6	26	38	0	0	40	100
0.3	18	28	0	0	28	100
0.15	12	20	0	0	18	100
0.075	4	10	0	0	8	93

Proportion of CA#1 (12.5mm)	Proportion of CA#2 (6.3mm)	Proportion of Dust (<4.75mm)	Proportion of Mineral Filler	RMSE	CAR	FAC	FAF	FM
31	4	63	2	9.78	0.5217	0.4896	0.4904	4.8787
31	5	62	2	9.43	0.52	0.4889	0.491	4.9124
31	6	61	2	9.1	0.5184	0.4903	0.4917	4.9461
31	7	60	2	8.77	0.5168	0.4906	0.4923	4.9798
32	1	65	2	10.45	0.5166	0.4891	0.4893	4.8148
32	2	64	2	10.09	0.5149	0.4894	0.4899	4.8485
32	3	63	2	9.73	0.5133	0.4896	0.4904	4.8822
32	4	62	2	9.39	0.5118	0.4899	0.491	4.9159
32	5	61	2	9.05	0.5104	0.4903	0.4917	4.9496
32	6	60	2	8.72	0.5089	0.4906	0.4923	4.9833
33	1	64	2	10.04	0.5061	0.4894	0.4899	4.8521
33	2	63	2	9.69	0.5047	0.4896	0.4904	4.8858
33	3	62	2	9.34	0.5034	0.4899	0.491	4.9195
33	4	61	2	9	0.5021	0.4903	0.4917	4.9532
33	5	60	2	8.68	0.5008	0.4906	0.4923	4.9869
34	1	63	2	9.64	0.4961	0.4896	0.4904	4.8894
34	2	62	2	9.3	0.495	0.4899	0.491	4.9231
34	3	61	2	8.96	0.4939	0.4903	0.4917	4.9568
34	4	60	2	8.63	0.4928	0.4906	0.4923	4.9905
35	1	62	2	9.25	0.4865	0.4899	0.491	4.9267
35	2	61	2	8.91	0.4856	0.4903	0.4917	4.9604
35	3	60	2	8.59	0.4847	0.4906	0.4923	4.9941
36	1	61	2	8.87	0.4779	0.4903	0.4917	4.9639
36	2	60	2	8.54	0.4771	0.4906	0.4923	4.9976
37	1	60	2	8.5	0.4693	0.4906	0.4923	5.0012

Fig 3 Screenshot for revised dust gradation

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7. Conclusion

This article has presented the importance of gradation in the construction of flexible pavements, especially the wearing course. Excel spread sheet are being used to

select appropriate blend from a number of stockpiles. There are no integrated tools available combining different philosophies of aggregate blending. A novel attempt is made in this direction to develop an integrated tool to fill the research gap. Accordingly, a GUI based tool in C# was developed and the use of software was demonstrated. The Dust is found to influence the JMF. Initial run of the software has revealed that blends fulfilling only MoRTH could be generated. This shows the recommendation of Bailey were stringent. On the other hand, when the gradation of was altered, blends fulfilling both MoRTH and Bailey could be generated. Therefore this innovative tool would be of great help to practicing engineers to arrive at most appropriate blend to be used in the mix design.

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