Gradation and performance research of cold recycled mixture

Hui Yao[1], Liang Li[2], Hua Xie[3], Han-Cheng Dan[4] and Xiao-Li Yang[5]

[1]Doctoral candidate, School of civil engineering and architecture, Central South University, Changsha, Hunan Province, People's Republic of China,+86(135)7481-2500; jianxin_yaohui@163.com
[2]Professor, School of civil engineering and architecture, Central South University, Changsha, Hunan Province, People's Republic of China,+86(731)8887-6678; liliang_csu@163.com
[3]Doctoral Candidate, Hole School of Construction, Department of Civil and Environmental Engineering, 5-080 Markin/CNRL Natural Resources Engineering Facility, University of Alberta, Edmonton, AB, Canada; xh316@hotmail.com
[4]Doctoral candidate, School of civil engineering and architecture, Central South University, Changsha, Hunan Province, People's Republic of China,+86(135)4964-1242; danhancheng@163.com
[5]Professor, School of civil engineering and architecture, Central South University, Changsha, Hunan Province, People's Republic of China,+86(731)8265-6428; yangxl@mail.csu.edu.cn

ABSTRACT: Cold in-place recycling was adopted for a project in China due to the availability of reclaimed asphalt pavement (RAP). Based on the Foshan loop project in Guangdong, the gradation design of cold recycled mixtures (CRM) was optimized by the Bailey Method. Emulsified asphalt and cement were used as additives. Then, the screenings of aggregates in RAP and RAP were analyzed and compared. Additionally, new aggregates and cement were added to dispose the framework structure of the cold recycled mixture, and modified Marshall Tests conducted to determine the optimum amount of emulsified asphalt and water, by which cold recycled mixture was formed and performance experiments of asphalt mixture carried out. Eventually, the results show that the gradation design of cold recycled mixture needs to be adjusted by the screening of aggregates in RAP. Also, cold recycled mixture is suitable for highway sub-grade and pavements of low-grade roads.

INTRODUCTION

Cold recycled technology is one of the promising and cost-effective pavement maintenance measures, besides it can protect the biological environment and create more social benefit. According to the pavement structural style, it can be divided into asphalt pavement recycling and cement pavement recycling; according to the position of recycling, it can be divided into the surface layer recycling, base layer recycling and sub-base layer recycling; according to regeneration mode, it can be divided into the hot recycling and cold recycling; according to the place of recycling, it can be divided into cold in-place recycling and central plant cold recycling (Junyi Ma, 2005). Cold recycled technology of asphalt pavement refers to the method of recycling and repeatedly using the old asphalt materials of the road and adding partially new or fine aggregate and appropriately utilizing a certain amount of stable additives and water. Finally, the series of processes is completed and a structural layer is again formed under natural surroundings.

In this research, the CRM gradation was optimized by not only adding new aggregates, and the emulsified asphalt and cement as additives but also utilizing the Bailey Method. Furthermore, the performance tests of CRM are carried out. Eventually, adjusting the CRM gradation requires the screening of the aggregates in RAP. CRM is suitable for the highway sub-grade and pavements of low-grade roads, which can be brought forward.

BAILEY METHOD

Generally speaking, considering the alternative gradation of CRM in natural temperature, engineering personnel usually reckon using experience to mix the reclaimed asphalt pavement (RAP) material. The pavement performance of asphalt mixture mainly depends on the aggregates construction and interlocked-denseness of the coarse aggregates. However, it is difficult to design the dense framework structure. American Illinois Department of Transportation Robert Bailey put forward Bailey the Method after accumulated experience during the process of aggregates design and construction (Yingjie Yuan, 2004).

Before the Bailey Method, there are two classifications on coarse and fine aggregates. One defines 4.75mm as its watershed; the other defines 2.36mm as a criterion. This holds true for to all particles sizes. Actually, coarse and fine aggregates are relative, and it is improper to apply this criterion for aggregates of nominal maximum primary sizes of 4.75mm. Conversely, the Bailey Method brings improvement, which dynamically determines the classification of aggregates. In other words, the criterion of coarse and fine aggregates depends on the Primary Control Sieve (Pcs). Table 1 and Table 2 give all kinds of sieves and parameters of several types asphalt mixtures. In the table below NMPS is nominal maximum primary size, F_1 is the first control sieve, F_2 is the second control sieve, Pcs=NMPS×0.22, Hs=NMPS×0.5, $F_1=P_{cs}\times0.22$, $F_2=F_1\times0.22$, $F_{ac}=P_{F1}/P_{Pcs}$, $F_{af}=P_{F2}/P_{F1}$, and $CA=(P_{hs}-P_{cs})/(100-P_{hs})$. According to the definition of Superpave, nominal maximum primary size is the previous sieve size at which the passing percentage is more than 10%. Coefficient of equation 0.22d is determined from experience, and the voids in the coarse aggregates depend on the particle shape and sizes. If three particles are of circle shapes, the void is 0.15d; if they are two circles and one flat shape particles, the void is 0.20d; if one circle and two flat shape particles are involved, the void is 0.24d and if all three particles are flat in shape, the void is 0.29d. Therefore, coefficient 0.22d is the average of values.

Table 1. Three Parameters and Pcs

NMPS(mm)	25(mm)	19(mm)	12.5(mm)	9.5(mm)
Pcs(mm)	4.75	4.75	2.36	2.36
Hs(mm)	12.5	9.5	4.75	4.75
CA	$(P_{12.5}-P_{4.75})/(100-P_{12.5})$	$(P_{9.5}-P_{4.75})/(100-P_{9.5})$	$(P_{4.75}-P_{2.36})/(100-P_{9.5})$	$(P_{4.75}-P_{2.36})/(100-P_{9.5})$
F1(mm)	1.18	1.18	0.6	0.6
Fac	$P_{1.18}/P_{4.75}$	$P_{1.18}/P_{4.75}$	$P_{0.6}/P_{2.36}$	$P_{0.6}/P_{2.36}$
F2(mm)	0.3	0.3	0.15	0.15
Faf	$P_{0.3}/P_{1.18}$	$P_{0.3}/P_{1.18}$	$P_{0.15}/P_{0.6}$	$P_{0.15}/P_{0.6}$

Table 2. Value range of dense gradation

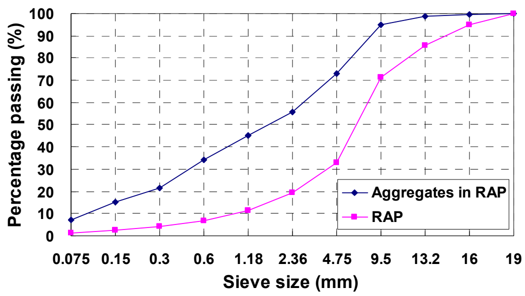
NMPS(mm)	37.5	25.0	19.0	12.5	9.5	4.75
CA	0.80-0.95	0.70-0.85	0.60-0.75	0.50-0.65	0.40-0.55	0.30-0.45
Fac	0.35-0.50	0.35-0.50	0.35-0.50	0.35-0.50	0.35-0.50	0.35-0.50
Faf	0.35-0.50	0.35-0.50	0.35-0.50	0.35-0.50	0.35-0.50	0.35-0.50

COLD RECYCLED MIXTURE GRADATION DESIGNS

RAP sieve tests

Cold in-place recycling (CIR) has been applied on China's National Highway No.325. Compositions of the RAP are really complicated, because they include aged asphalt blocks, coarse and fine aggregates. Aggregates are wrapped by asphalt, which sticks to the blocks. In practical application, the RAP is usually utilized as aggregates, so its gradation and original status were analyzed. After milling-planning the maximum particle size of asphalt mixture was less than 30mm. Because the aged asphalt was in the RAP, blocks would be soft at high temperature which might affect the results of the screening. Thereby, dry specimens would be gained from natural weathering rather than drying.

In order to separate the asphalt and aggregates, the centrifugal separation method was utilized by the trichloroethylene extraction test, by which the content of asphalt was determined. Then, the sieving of aggregates in RAP was used to compare with screening of RAP. For the sake of getting the exact content of asphalt, parallel experiments were processed and the burning method was conducted to obtain asphalt content, which is 4.8%. Results are shown in Fig.1. All experiments were measured in the laboratory following the procedure outlined in JTG F41-2008.



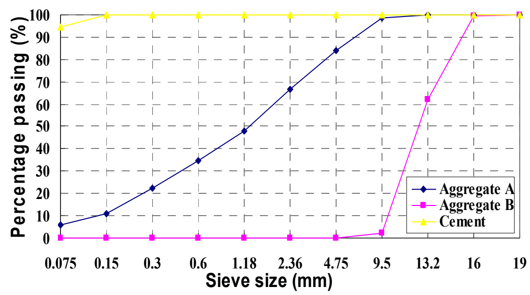


Fig.1. Screening curves of aggregates in RAP and RAP (Left hand side)

Fig.2. Gradation of new aggregates and cement (Right hand side)

Fig.1 shows the relationship between aggregates in RAP and the complete RAP itself. The gradation curve of RAP basically belongs to the area of base gradation by standard definition. Compared with the screening of the RAP, the fine aggregates content of aggregates in the RAP has been apparently increased. This demonstrates that the aggregates of the road have been crushed by the load from the vehicle wheels and from the milling-planning machine. The difference between the two screening curves is due to the asphalt content. The more asphalt content there is, the more the agglomeration will manifest. However, whether actual particle composition of the mixtures will be close to the screening of RAP or the screening of aggregates in RAP needs to be determined.

New aggregates properties

Based on the screening results of the RAP, new aggregates need to be added. The Specific Capacity Bottle Method in Highway Engineering was adopted to measure the apparent density. The apparent density value of aggregate A is 2.651g/cm^3, and the apparent density value of aggregate B is 2.729g/cm^3. Screening results of the new aggregates are shown in Fig.2. The experiment was measured in the laboratory following the procedure outlined in JTJ052-2000.

Gradation scheme

RAP performance, new aggregate properties and the cement effect were synthesized and analyzed. Gradation A of the CRM was adjusted to a dense gradation AC-16 (Medium Grain Type). The CRM A was composed of 70% RAP, 27% new aggregate A and 3% cement. Gradation results of CRM are shown in Fig.3. After adjusting the gradation of CRM by the Bailey Method, the collocation of coarse and fine aggregates was reasonable and a dense framework structure was formed. Moreover, relative parameters of the Bailey Method were calculated. The results are as follows: nominal maximum primary size is 16mm, CA=0.60, F_{ac} =0.49 and F_{af} =0.49.

Likewise, gradation B of CRM was adjusted to a dense gradation AC-16 (Medium Grain Type) and it was composed of 70% RAP, 28% new aggregate B and 2% cement. Gradation results of the CRM are shown in Fig.4. The relative parameters of the Bailey Method were calculated. The results are as follows: nominal maximum primary size is 16mm, CA=0.51, F_{ac}=0.63 and F_{af} =0.50.

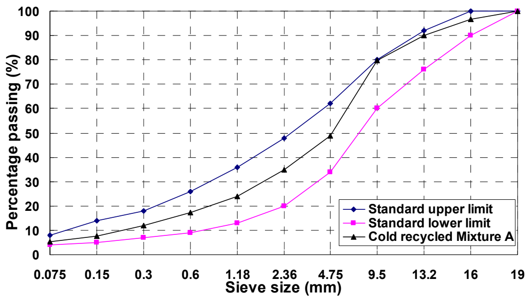


Fig.3. **Gradation A of CRM**

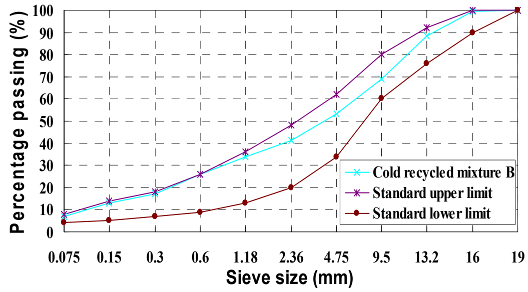


Fig.4. **Gradation B of CRM**

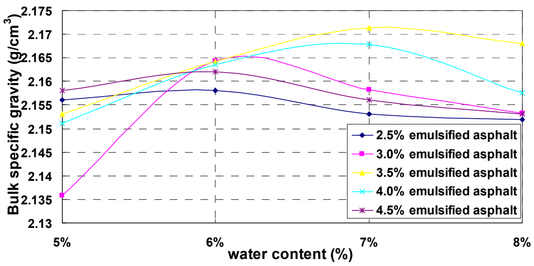
To wrap it up, when the Bailey Method was applied into the dense gradation, various parameter values of the CRM were all in the range of specification values with reference to Table 2. Therefore, gradations A and B of the CRM can be considered as rational gradations.

Determination of optimum asphalt and water content

Considering the setting time and temperature effects of cement hydration, Marshall Tests were needed to modify the materials and the main modifications were as follows: First, RAP, new aggregates and cement were put into the mixer with low velocity blending, and some water was slowly added into the mixer. Then, the emulsified asphalt was added into the mixer. Finally, Marshall Samples were formed. Samples were hit by two facets for two times. One is when mixtures were added into mould; the other is initial setting time of cement. The times of the hit-solid needed to be reduced by half, while knockout and maintenance of samples were processed after the second hit-solid. Various contents of emulsified asphalt (2.5%, 3.0%, 3.5%, 4.0% and 4.5%) and water were applied. Besides, six samples were in a group and a 72h maintenance was carried out at a ventilation oven temperature of 40°C, which ensures that mixtures did not contain water (Gao Ying, 1998, Hong Tang, 1999 and Zhang Si-yuan, 2000).

(1) Determination of optimum water content

The compaction effect and the molding speed of the emulsified asphalt mixture samples would be affected by the water content, which is usually between 2% and 8% for the medium grain aggregates. When the mixture had more fine aggregates and powders, the water content would be higher and vice versa. Besides, modified Marshall Tests would be undertaken with different contents of emulsified asphalt and water. The optimum water content of CRM A and CRM B could be gained from the curves of their bulk density relationship. The results are shown in Fig.5 and Fig.6.



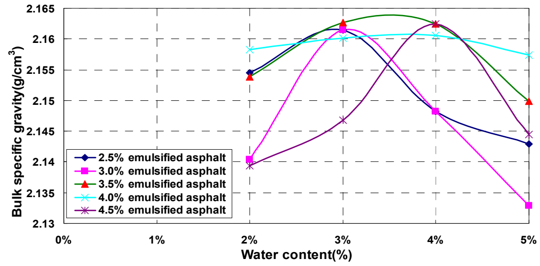


Fig.5. Density and water content of various emulsified asphalt content (Gradation A, Left hand side)

Fig.6. Density and water content of various emulsified asphalt content (Gradation B, Right hand side)

(2) Determination of optimum asphalt content

Marshall Test's samples were made at optimum water content of various emulsified asphalt with the method being the same as above. Thereby, the relative indexes of CRM A and CRM B could be obtained from the modified Marshall Tests. The results are shown in Table 3 and Table4.

Table 3. Relative indexes of various emulsified asphalt content (Gradation A)

Emulsified asphalt content (%)	Optimum water content (%)	Bulk specific gravity (g/cm3)	Marshall Stability (KN)	Volumes of air voids (%)	Flow value (mm)	Voids in mineral aggregates (%)	Voids filled with asphalt (%)
2.5%	5.8%	2.162	11.56	4.89	3.481	10.892	55.085
3%	6.2%	2.165	12.08	3.71	3.525	10.209	63.668
3.5%	7%	2.171	13.77	2.39	3.658	9.389	74.559
4%	6.8%	2.163	12.23	1.70	3.706	9.198	81.537
4.5%	6.0%	2.162	11.83	0.69	3.759	8.694	92.016

Table 4. Relative indexes of various emulsified asphalt content (Gradation B)

Emulsified asphalt content (%)	Optimum water content (%)	Bulk specific gravity (g/cm3)	Marshall Stability (KN)	Volumes of air voids (%)	Flow value (mm)	Voids in mineral aggregates (%)	Voids filled with asphalt (%)
2.5%	2.8%	2.160	10.56	6.06	3.492	13.062	45.936
3%	3.0%	2.161	11.18	4.88	3.601	12.377	52.519
3.5%	3.5%	2.164	11.44	3.71	3.658	11.713	59.765
4%	3.8%	2.161	10.21	2.80	3.706	11.297	66.389
4.5%	4.0%	2.158	10.32	1.88	4.185	10.884	73.499

MECHANICAL PERFORMANCE OF COLD RECYCLED MIXTURE

Cold recycled mixture usually has been utilized for the sub-grades of highways and pavements of low-grade roads, and it must withstand traffic loads and the repeated effect of natural factors. Therefore, in order to study the distortion and shear damage, an analysis and evaluation of the compositional structure and materials performance are necessary.

Compressive strength is the basic index of material performance, and it is easy to form experimental specimens and undertake experiments during the procedure. Based on the experimental method for unconfined compressive strength of inorganic binders, the laboratory test is carried out. The cleavage strength is one of the mechanical performance indexes of cement stability mixtures. In order to further study strength change laws, tests on the CRM would be carried out. Besides, the resilient modulus is a significant parameter of pavement design, and it has the tremendous influence on the structural performance of the pavement. All experiments results are shown in Table 5, Table 6 and Table 7. All experiments were measured in the laboratory following the procedure outlined in JTJ052-2000.

Table 5. Compressive strength results of cold recycled mixture (20℃)

Components of asphalt mixture	Compressive strength (MPa)	Compressive strength (MPa)	Compressive strength (MPa)
Age (day)	3	7	28
Normal Marshall Tests with RAP	1.9	2.7	3.2
Aggregates in RAP, aggregates, cement and emulsified asphalt (Gradation B)	2.3	3.5	4.5
RAP, aggregates, cement and emulsified asphalt (Gradation A)	2.2	3.4	4.2

Table 6. Cleavage strength results of cold recycled mixture (15℃)

Components of asphalt mixture	Cleavage strength (MPa)	Cleavage strength (MPa)	Cleavage strength (MPa)
Age	3	7	28
Normal Marshall Tests with RAP	0.10	0.19	0.35
Aggregates in RAP, aggregates, cement and emulsified asphalt (Gradation B)	0.13	0.30	0.54
RAP, aggregates, cement and emulsified asphalt (Gradation A)	0.12	0.28	0.48

Table 7. Modulus resilience results of cold recycled mixture (20℃)

Components of asphalt mixture	Modulus of resilience (MPa)	Modulus of resilience (MPa)	Modulus of resilience (MPa)
Age	3	7	28
Normal Marshall Tests with RAP	1015	1166	1316
Aggregates in RAP, aggregates, cement and emulsified asphalt (Gradation B)	1350	1564	1589
RAP, aggregates, cement and emulsified asphalt (Gradation A)	1230	1423	1506

CONCLUSIONS

In the application of the Bailey method, adjusting the gradation requires appropriate target gradations and new aggregates. Then, three parameters of the Bailey method ensure that the volume properties and construction expansibility of CRM is not compromised. Although the Bailey method has comprehensive applicability for various mixtures, the gradation design of specific mixtures has its own features. Furthermore, only by synthesizing the gradation type, material characteristics and the Bailey method, a good asphalt mixture can be designed. The research results showed that:

(1) The volume of air Voids and Voids in Mineral Aggregates of samples is all small, and CRM A contains more fine aggregates, which is inconsistent with the gradation A adjusted by the Bailey Method. Adjusting the gradation of CRM creates conditions of optimum emulsified asphalt content and optimum water content.

(2) Gradation designing of CRMs can create deviations from the Chinese Technical Specifications, which assumes the content of emulsified asphalt is 4%, and the dynamic unification of emulsified asphalt and water content is realized.

(3) The mechanical performance of CRM B is superior to that of CRM A. Adjusting the CRM gradation requires making use of the screening of aggregates in RAP. Moreover, the modified Marshall Tests can improve the performance of CRM compared with normal Marshall Tests.

(4) Cold recycled mixture is suitable for highway sub-grades and pavements of low-grade roads.

REFERENCES

Junyi Ma. (2005). "Research and application of cold recycling old asphalt mixture material on base course." Master thesis, Chang'an University, Xi'an.

Yingjie Yuan. (2004). "Research on Rheological Characteristics of Asphalt Mortar and Gradation Optimization Based on Superpave." Ph.D.dissertation, Chang'an University, Xi'an.

Gao Ying, Ling Tianqing, Qiao Guanhua and Xu Zhihong. (1998). "Proportioning of Cement-emulsified Asphalt Mixture." Journal of Tongji Universtiy, Vol.26(6):674-676.

Hong Tang and Xingyu Peng. (1999). "Gradation Design of cation emulsified asphalt." LiaoNing Communication Science and Technology, Vol.22(4):13-16.

Zhang Si-yuan and Wei Jian-min. (2000). "Research on the Optimum proportioning and Construction Method of Cement-Emulsified Bitumen Mixture." Journal of Chongqing JiaoTong Institute, Vol.19(1):72-75.

Development of blending chart for different degrees of blending for Reclaimed Asphalt Pavements in HMA

Prashant Shirodkar[1], Dr. Yusuf Mehta[2], Aaron Nolan[3], Khyati Sonpal[4], Eric Dubois[5]

[1] Graduate Research Assistant, Department of Civil and Environmental Engineering, Rowan University Glassboro, NJ 08028, USA. E-mail: shirod68@students.rowan.edu
[2] Associate Professor, Department of Civil and Environmental Engineering, Rowan University Glassboro, NJ 08028, USA. E-mail: mehta@rowan.edu
[3] Research Associate, Department of Civil and Environmental Engineering, Rowan University Glassboro, NJ 08028, USA. E-mail: nolan@rowan.edu
[4] Graduate Research Assistant, Department of Civil and Environmental Engineering, Rowan University Glassboro, NJ 08028, USA. E-mail: sonpal23@students.rowan.edu
[5] Undergraduate Student, Department of Civil and Environmental Engineering, Rowan University Glassboro, NJ 08028, USA.

ABSTRACT: The demand to utilize higher percentages of reclaimed asphalt pavement (RAP) in the construction of hot mix asphalt (HMA) pavements continues to rise. Utilization of RAP in HMA is an environmentally friendly and cost effective method of recycling. At high percentage of RAP properties of RAP binder and its interaction with virgin binder plays critical role. Researchers have consistently shown that when RAP is mixed with virgin binder and aggregates, partial blending occurs, that is, something between 100% blending and the "black rock" effect occurs. Impact of partial blending on new virgin binder content is apparent which may cause under-asphalted mixture, resulting in poor pavement performance. Also influence of partial blending on final grade of RAP mix and allowable percentage of RAP has not been evaluated. The purpose of this paper is to develop the blending chart for different degree of blending to study the impact of partial blending on final grade of blended binder. To achieve the objective, blending chart for 100%, 70% and 50% RAP has been developed for PG 70-28 and PG 58-28 binder by carrying out binder study.

INTRODUCTION

The demand to utilize higher percentages of Reclaimed Asphalt Pavement (RAP) in the construction of hot mix asphalt (HMA) pavements continues to rise (NAPA, 1998). In the some of the states including New Jersey the mix is designed using virgin aggregates and virgin binder. After the design binder content is determined, the virgin binder content is established by giving full credit to the RAP binder, assuming 100%