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# Research on the Parameters of Environment-Friendly Recycled Road Materials

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**Abstract**

The feasibility of propagating road materials in the use of contracture wastes especially contented great amount waste bricks were researched in three aspects: Performance of recycled aggregate, mechanical properties of renewable road materials, compression - splitting indexes. Conclusions are as following: recycled aggregates contenting great amount waste bricks in place of natural aggregates are feasible from the point of view on technical and technological. The performances of recycled aggregates have a significant impact on properties of renewable road material. Whether it is cement stabilized RCA material or cements stabilized RCBA material, age and cement in the age-dose studies, with the increase in cement dose, mechanical properties growth trends are similar. Compared to unconfined compressive strength and resilient modulus, splitting strength is much closed in terms of growth trends or Growth value at the cement doses or ages. Good Relevance correlation are existed among resilient modulus, compressive strength and splitting strength: $\sigma_{sp90} = 0.17R_{c7}$,RCA: $\sigma_{sp90} = 0.20R_{c7}$.

**Keywords:** Road engineering, Recycled road materials, Experimental research, Basic properties, Relevance

## 1. Introduction

With the development of urban construction, and the Construction of substantial reconstruction, Extension, Conversion and New Projects, on the one hand, large amounts of construction waste inevitably produce inevitably from the demolishment of existing buildings. On the other hand, a large number of building material is necessitated for the construction of large amounts new buildings. Therefore, how to resourceful disposal these construction wastes is one pressing problem. In recent years, Resource Utilization of construction waste is considered as one of the most important attempt of sustainable development(Nik D Oikonomou, 2007). a large number of experiments and practice proved that recycled aggregate has a good pavement performance(ZHANG Chao, 2002, Chi Sun Poon, 2006) the Utilization of recycled aggregate in road engineering is one of effective ways to deal with construction waste. However, compared with natural aggregate as a result of the exit of large amounts of old cement mortar, pores and micro-cracks, recycled aggregate has certain characteristics. Especially, the e abrasion value and Moisture Content of recycled aggregate is much higher than the natural aggregate(Sumeda Paranavithana, 2006), which caused certain adverse effects for the properties of road material.

In recent years, some studies on application of recycled aggregate in road engineering have been made and have made some research results, For example, Degroot DJ (1998) successfully used the recycled aggregate in highway construction, construction waste was successfully applied in the construction of an office building, P. Gribl, et al(1998) research shows that the building had a goodperformance. But all these researches only limited in the simple application of higher intensity waste concrete block (ZHU Hai-yan, 2006, Farid Debieb, 2008, B Juric, 2006, Nik. D. Oikonomou, 2005), large-scale, resourceful treatment of crushed brick which is one of the major components of construction waste was seldom involved. Based on the joint use of recycled concrete aggregate (hereinafter referred to as “RCA”) recycled brick aggregate (hereinafter referred to “RCBA”), recycled road materials had been prepared to back for the actual project. And studying its strength properties and Conversion Relations among its mechanical properties and through a complex analysis, the distribution of strength properties of recycled road material will be studied.

**2. Study on characteristics of recycled aggregate**

In accordance with the relevant norms or standards, the studies of performances were done to aim at the two types of RCA, RCBA (m crushed brick: m waste concrete = 1:1). Experiment results are given in Table 1 below.

Table1 Performance parameters of recycled aggregate

Fig.1. Curve of performance of recycled aggregate and its size and original concrete strength

As show in figures 1(a), 1(b), 1(c) and 1(d), they can be concluded that:

(1) To some extent, wear value of recycled aggregate can reflects the relative content of the old cement. It can be seen from table 1, about 1/3 old cement mortar exists in RCA. Akash Rao, etc (2006) found that RCA had about 30%old cement mortar in weight. This research result much closed to this article's. The strength of cement mortar is little lower than aggregate's. From this point, the strength of recycled aggregates should lower than natural aggregates'.

(2)Results indicate that the crushing value of recycled coarse aggregate decreased as the strength of original concrete increased (fig.1 (a)). With the original concrete strength increased, the quality of recycled aggregate is better.

(3) As a result of the erosion of rain or wet weather, construction wastes often contain substantial moisture with long-term piled up. Recycled aggregate prepared from construction wastes also contain some moisture in the stacking process, which would impact optimum moisture content of mixture and water consumption of recycled road materials. Thus, it is necessary to test moisture content of recycled aggregate. As can be seen from table 1, moisture content of RCBA is slightly higher than RCA's, it mainly due to the more pores in the internal of crushed brick, which pay the role of natural "reservoir" in humid environment.

(4) Aggregate size itself and gradation of original concrete combined effect the water absorption of recycled concrete coarse aggregate of (Figure 1(b)). Under circumstances of the same aggregate size, water absorption of RCBA higher than RCA's, it mainly due to its incompact structure, the strength is lower than RCA's. The grade of original concrete used in construction is generally lower than C30, in the intensity levels; the water absorption of recycled aggregate is generally high and shows an uncertain regularity.

(5) (i) Apparent density of coarse aggregate is greater than the apparent density of fine aggregate; (ii) Apparent density of RCA is higher than the apparent density of RCBA. The apparent density of recycled aggregate has business with original concrete strength and aggregate size. As can be seen from Figure 1c, the apparent density of recycled aggregate increased as the aggregate and the strength of original concrete size increased.

(6)As show in table 1, mud content of recycled coarse aggregate much larger than natural coarse aggregate's. According to the recent study, mud content of recycled coarse aggregate decreased as the strength of original concrete increased (Figure 1d). It is worth noting that the mud particles in the old cement mortar is different from those which contained in natural coarse aggregate, which have certain activity to participate in hydration (J.M.Khatib,2005).

**3. Mechanical properties of recycled road material**

The main materials used in this research were construction wastes generated from the building removal in Kunming city, China. After crushing, screening process, construction wastes were prepared into two types of recycled aggregate (performance parameters in Table 1), that is, RCA, RCBA ($m_{\text{crushed brick}}$: $m_{\text{waste concrete}}$ = 1:1). The main use way is given in table 2 below.

Table2Use table of recycled aggregate

*3.1 Optimum gradation*

(1)Optimum gradation of recycled Subgrade material: $m_{37.5\text{-}53mm}$: $m_{19\text{-}37.5mm}$:$m_{4.75\text{-}19mm}$:$m_{<4.75mm}$=2:3:1:4;

(2)Optimum gradation of recycled Subbase material: $m_{19\text{-}37.5mm}$:$m_{4.75\text{-}19mm}$:$m_{<4.75mm}$=4:3:3;

(3)Optimum gradation of recycled Base material: $m_{19\text{-}31.5mm}$:$m_{4.75\text{-}19mm}$:$m_{<4.75mm}$=4:3:3.

*3.2 Compaction characteristics of mixture of recycled aggregate*

Dosing 4% cement dosage, Compaction Tests were made in use of RCA and RCBA according with Gradation designed in §2.1. Through parallel experiment, the test result is shown in fig.2, fig.3.

Fig.2 Moisture content - dry density curve of recycled Subgrade material

Fig.3 Moisture content - dry density curve of recycled base material

As shown in fig.3, the maximum dry density of recycled base materials is 1.99g/cm$^3$, and the optimum water content is 8.7%; the maximum dry density of recycled base materials is 2.11g/cm$^3$, and the optimum water content is 8.1%. With the content of crushed increased, the value of maximum dry density and maximum dry density of mixture become smaller. Therefore, the maximum dry density and optimum water content of Cement Stabilized Recycled Aggregate mixture are related to the water absorption of aggregate, the greater the water absorption of aggregate, the greater of the maximum dry density and optimum water content of cement stabilized recycled aggregate mixture.

*3.3 Influence factors research and comparative analysis of compressive strength*

As shown from fig.4, there was a good linear regression relationship between the unconfined compressive strength of Cement stabilized recycled aggregate in 7d, 28d age, the Regression Equation is shown in table 3.

Fig.4Linear regression trend intensity growth of recycled road materials

Table3 Regression relationship between compressive strength and cement dose

As shown in fig.4, with the cement dosage increased, unconfined compressive strength in both 7d and 28d age has a tendency to increase, and for recycled road materials prepared by RCBA, the growth trend of compressive strength in 28d age greater than 7d age's; but for recycled road materials prepared by RCBA, the growth trend of compressive strength was basically identical. This may be because high porosity in crushed brick and hydration of unhydrated cement in recycled fine aggregate.

*3.4 Influence factors research and comparative analysis of rebound modulus*

As shown from fig.5, there was a good linear regression relationship between the resilient modulus of Cement stabilized recycled aggregate in 7d, 28d age, the Regression Equation is shown in table 4.

Fig.5Linear regression trend resilient modulus growth of recycled road materials

Table4 Regression relationship between rebound modulus and cement dose

As shown from fig.5, in the research scope of age and cement dose, with the cement dose increased, either Cement Stabilized RCA or Cement Stabilized RCBA, the growth trend of rebound modulus is similar to compressive strength's, that is completely in conformity with the Features of cement-stabilized materials.

*3.5 Influence factors research and comparative analysis of splitting strength*

The test results of splitting Strength in 7d and 28d age can be seen from fig.6.

Fig.6. The growth trend of recycled road materials

As shown from fig.6, in the research scope of age and cement dose, with the cement dose increased, either Cement Stabilized RCA or Cement Stabilized RCBA, the rebound modulus increases linearly (the regression equation can be seen from table 5), and the growth trend is similar to compressive strength's and rebound modulus', this results confirm the correctness of this three experiments.

Table5 Regression relationship between splitting strength and cement dose

Founded in the experiment, regression relationship between the splitting strength and ages is Suitable for power function regression, the Regression Equation is shown in table 6.

Table6 Regression relationship between splitting strength and age

**4. Complexity analysis of unconfined compressive strength**

As shown in figure 7, test-point spread from 2 to10 MP, every strength value in 60 Specimens is different, showing a state of maximum complexity. The statistical analysis of test results can be seen from Table 7, Statistics interval is MP, and statistical frequency is 60. We can see from Figure 8, in the Interval of test results, compressive strengths are in line with the laws of Extreme Value Distribution.

Fig.7Scattergram of unconfined compression strength test

Table7 Reset of statistical analysis

Fig.8Extreme value distribution of unconfined compression strength test

According to the most complicated principle, normal distribution expression is derived as follow:

$$C = -\int N f(x) \ln f(x) dx \quad \cdots \quad \cdots\cdots \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \ (1)$$

Thinking average value of variable is limited, then:

$$u = \int_a^b x f(x) dx \cdots\cdots \quad \cdots\cdots \quad \cdots\cdots\cdots \ (2)$$

Integral of the percentage of every strength value of specimens in overall specimens' strength specimens is 1, that is:

$$1 = \int_a^b f(x) dx \cdots \quad \cdots\cdots \quad \cdots\cdots\cdots\cdots\cdots \ (3)$$

The Conditions of shape functions is:

$$1=\int_a^b \exp\left(-\frac{x}{\beta}\right)f(x)dx \cdots\cdots \qquad \cdots\cdots\cdots\cdots \qquad \cdots (4)$$

Constructing new function *F*:

$$F=-\int f(x)\ln f(x)dx+k_1\left(\int xf(x)dx-u\right)+k_2\left(\int f(x)dx-1\right)+k_3\left[\exp\left(-\frac{x}{\beta}\right)f(x)dx-1\right]\cdots\cdots\cdots\cdots\cdots\cdots\cdots(5)$$

Where, $k_1$, k2, k3 are undetermined coefficient.

$$\frac{\partial F}{\partial f}=\frac{\partial\int f(x)\ln f(x)dx}{\partial f}+k_1\frac{\partial\left(\int xf(x)dx-u\right)}{\partial f}+k_2\frac{\partial\left(\int f(x)dx-1\right)}{\partial f}+k_3\frac{\partial\left[\int\exp\left(-\frac{x}{\beta}\right)f(x)dx-1\right]}{\partial f}=0 \quad \cdots(6)$$

The new function F is the compound of complex degree expression and all constraint conditions. It is clear that when F Reaching the Maximum, so is the complex degree C. F is functional of unknown function *f*, *f* can be obtained through Partial derivative of *F* on *f*, and makes it equal to zero, that is:

$$-(\ln f(x)+1)+k_1x+k_2+k_3\exp\left(-\frac{x}{\beta}\right)=0\cdots\cdots\cdots\cdots\cdots\cdots \qquad \cdots (7)$$

$$\ln f(x)=(k_2-1)+k_1x+k_3\exp\left(-\frac{x}{\beta}\right)\cdots\cdots\cdots\cdots\cdots\cdots\cdots \qquad \cdots (8)$$

$$f(x)=K\exp\left[k_1x+k_3\exp\left(-\frac{x}{\beta}\right)\right]\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \qquad \cdots\cdots (9)$$

Where, $K$=$k_2$-1. Simultaneous equations (9) and (1)-(3), coefficient $k_1$, $k_2$, $k_3$ can be determined, and The ultimate expression can be obtained as follow:

$$f(x)=\frac{1}{0.1\beta}\exp\left[-\frac{x}{\beta}-\exp\left(-\frac{x}{\beta}\right)\right]\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \qquad \cdots\cdots (10)$$

If the distance from extreme peak to 0is α, then, placing variables x-β. Then:

$$f(x)=\frac{1}{0.1\beta}\exp\left[-\frac{x-a}{\beta}-\exp\left(-\frac{x-a}{\beta}\right)\right]\cdots\cdots\cdots\cdots\cdots\cdots\cdots \qquad \cdots\cdots (11)$$

Combining with the Characteristics of recycled aggregate, α, β can be obtained by curve fitting, that is α=49.13, β=10.57.Then:

$$f(x)=\frac{1}{1.06}\exp\left[-\frac{x-49.13}{10.6}-\exp\left(-\frac{x-49.13}{10.6}\right)\right]\cdots\cdots\cdots\cdots\cdots \qquad \cdots\cdots\cdots\cdots (12)$$

Extreme value distribution is a skewed distribution, content of crushed brick are taken into account in the data analysis. All test pieces of recycled concrete aggregate strength concentrated in the extreme value distribution of the peak, the intensity value of its 5 Mp, statistical probability of 0.367; 4 ~ 6Mp in the test block of the statistical probability of 0.7 intensity; the remaining strength of test block, although more than 6 MP belonging to extreme value distribution but the right side of the tail, statistical probability of only 0.2. Therefore, it can be concluded that the path of renewable materials unconfined compressive strength value of 4 ~ 6 Mp mainly, of which nearly 5 Mp test the strength of the most representative pieces.

## 5. Correlation analysis of compression-splitting index

In order to find the inherent relationship among the strength indexes of recycled road materials for calculating indirectly other mechanical indicators after obtaining one index which more easily measured. From the comparative analysis of three strength indexes got from a lot of test, the paper found that good correlation exist among the three strength indexes regardless of ratio of mixture and length of curing age(as shown in fig.9). And the correlation can be analyzed in linear regression.

Fig.9Regression relationship between compressive strength and modulus rebound, spilt intensity

The relational expression of compression rebound Modulus (E0) and compressive strength (Rc) is as follow:

$E_O = 539.94 + 374.93\text{Rc}$ (Correlation coefficient: r=0.9507)………………… … (13)

The relational expression of splitting strength ( $\sigma_{sp}$ ) and compressive strength (Rc) is as follow:

$$\sigma_{sp} = -0.042 + 0.104\mathrm{Rc} \text{ (correlation coefficient: r=0.9478)} \qquad (14)$$

For RCBA, splitting strength in 90d age / compressive strength in 7d age is in a ratio of 0.14-0.22,the average ratio is 0.19, Standard deviation is 0.03.Considering the probability of 90%, comes to the formula as follow:

$$\text{RCBA: } \sigma_{sp90} = 0.17R_{c7} \qquad (15)$$

For RCA, splitting strength in 90d age / compressive strength in 7d age is in a ratio of 0.17-0.24,the average ratio is 0.21, Standard deviation is 0.04.Considering the probability of 90%, comes to the formula as follow:

$$\text{RCA: } \sigma_{sp90} = 0.20R_{c7} \qquad (16)$$

Through relationship above, splitting strength in 90d age can be calculated from compressive strength value in 7d age, which can reached the purpose of shortening test cycle and accelerating the design progress.

**6. Conclusions**

The performances of recycled aggregate and those influencing factors were studied systematically in this paper. And the author has studied the affection of performances of recycled aggregate to road materials. Through the complexity analysis of compressive strength, the paper holds that compressive strength of recycled road materials based mainly on 4-6 Mp. According to the study, regression relationship between the unconfined compressive strength, rebound modulus and cement dose is Suitable for linear regression; splitting strength and ages is Suitable for power function regression. Having given a correlation analysis for compression-splitting index, Good Relevance correlation are existed among resilient modulus, compressive strength and splitting strength: $\sigma_{sp90} = 0.17R_{c7}$ ,RCA: $\sigma_{sp90} = 0.20R_{c7}$, which reached the purpose of shortening test cycle and accelerating the design progress. For the further study, I personally think that the main research work can be carried out from the following three aspects:

(1) Shrinkage properties of recycled base material are worth further studying, for founding the effective measures to control them.

(2) Study thoroughly the affection of internal pore distribution of concrete foe strength of recycled concrete, durability and other properties.

(3) Exploring the fracture model of this kind of materials for the practical use of recycled research.

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List of table captions

Table 1. Performance parameters of recycled aggregate

| *Name* | | *wear value* | *crushing value* | *moisture content* | *water absorption* | *apparent density* | *mud content* |
|---|---|---|---|---|---|---|---|
| RCA | CA | 34.39% | 17.12% | 4.07% | 6.46% | 2420 kg/m$^3$ | 5.8% |
| | FA | / | / | / | 9.22% | 2090 kg/m$^3$ | / |
| | Water absorption of this gradation: 7.29% | | | | | | |
| RCBA | CA | 48.56% | 24.55% | 4.15 | 9.02% | 2390 kg/m$^3$ | / |
| | FA | / | / | / | 10.72% | 2010 kg/m$^3$ | / |
| | Water absorption of this gradation: 9.70% | | | | | | |
| NA | CA | 18.8% | 9.6% | / | 3.6% | 2630 kg/m$^3$ | 1.4% |
| | FA | / | / | / | 7.6% | 2620 kg/m$^3$ | / |

Table 2. Use table of recycled aggregate

| *Subgrade material* | *Subbase material* | *Base material* | |
|---|---|---|---|
| RCBA | RCA | RCA(Down) | *NA(Up) |

Note: "*" indicates that the project is not the content of this experimental study

Table 3. Regression relationship between compressive strength and cement dose

| *Regression Equation: y=a+bx* | *RCBA* | | *RCA* | |
|---|---|---|---|---|
| | 7d | 28d | 7d | 28d |
| a | 0.096 | 0.164 | 0.720 | 0.545 |
| b | 0.857 | 1.138 | 0.840 | 1.321 |
| s | 0.155 | 0.223 | 0.126 | 0.173 |
| r | 0.9977 | 0.9973 | 0.9955 | 0.9791 |

Note: y—compressive strength(Mp); x—cement dose(%)

Table 4. Regression relationship between rebound modulus and cement dose

| *Regression Equation: y=a+bx* | *RCBA* | | *RCA* | |
|---|---|---|---|---|
| | 7d | 28d | 7d | 28d |
| a | 125.857 | 175.030 | 41.464 | 117.404 |
| b | 414.501 | 495.447 | 529.088 | 636.243 |
| s | 175.957 | 240.207 | 64.927 | 161.146 |
| r | 0.9875 | 0.9896 | 0.9989 | 0.9955 |

Note: y—rebound modulus (Mp); x—cement dose (%)

Table 5. Regression relationship between splitting strength and cement dose

| *Regression Equation: y=a+bx* | *RCBA* | | | *RCA* | | |
|---|---|---|---|---|---|---|
| | 7d | 28d | 90d | 7d | 28d | 90d |
| a | -0.016 | 0.004 | -0.274 | -0.009 | -0.058 | -0.227 |
| b | 8.016 | 11.387 | 23.143 | 8.312 | 14.037 | 26.451 |
| r | 0.9984 | 0.9935 | 0.9981 | 0.9849 | 0.9934 | 0.9914 |

Note: y—splitting strength (Mp); x—cement dose (%)

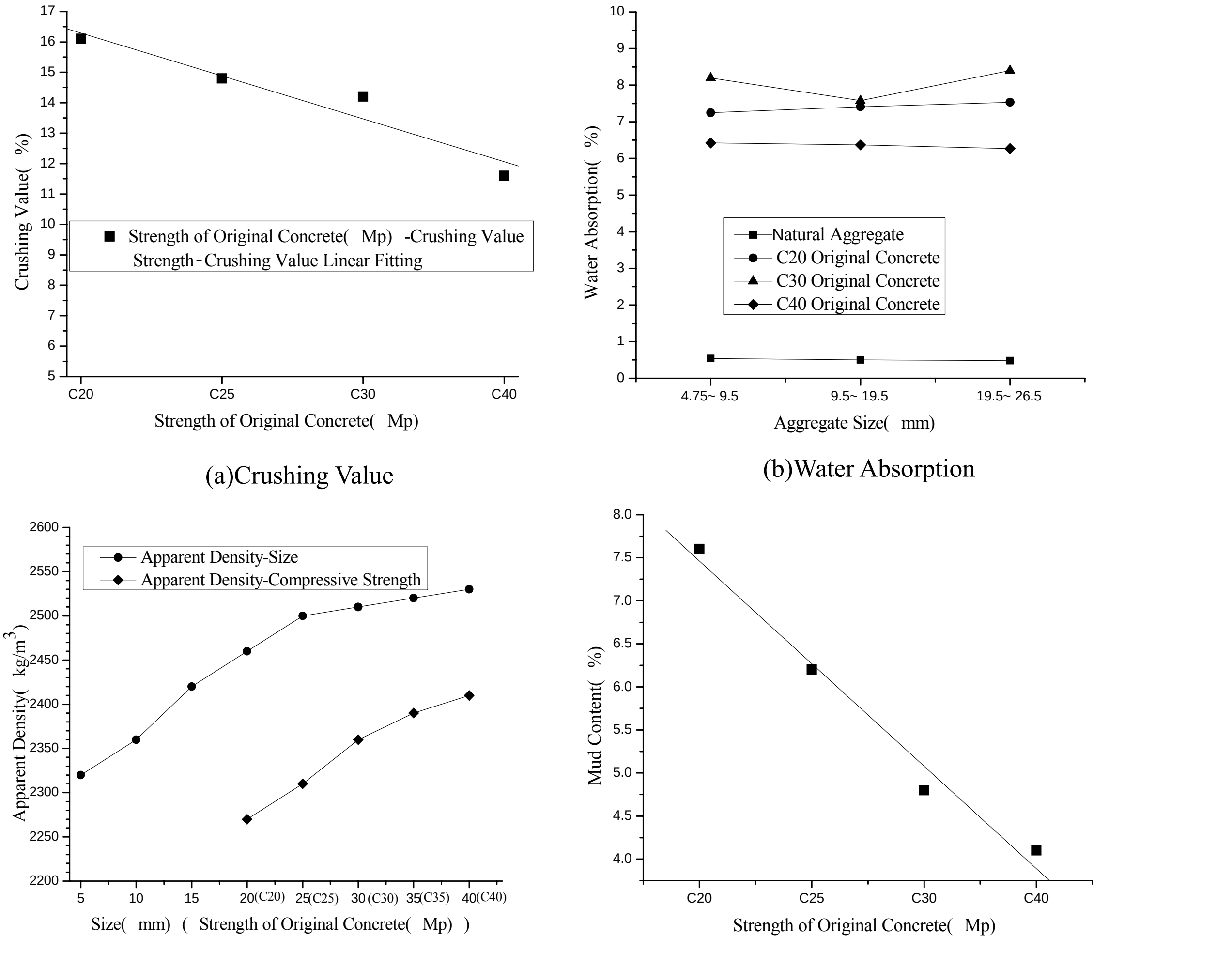
Table 6. Regression relationship between splitting strength and age

| *Regression Equation:* $y=ax^b$ | *RCBA* | | | | *RCA* | | | |
|---|---|---|---|---|---|---|---|---|
| | 3% | 4% | 5% | 6% | 3% | 4% | 5% | 6% |
| a | 0.135 | 0.154 | 0.214 | 0.264 | 0.139 | 0.145 | 0.195 | 0.261 |
| b | 0.268 | 0.335 | 0.301 | 0.294 | 0.299 | 0.372 | 0.367 | 0.347 |
| r | 0.9712 | 0.9923 | 0.9961 | 0.9556 | 0.9945 | 0.9857 | 0.9702 | 0. 9934 |

Note: y—splitting strength (Mp); x—age (d)

Table 7. Reset of statistical analysis

| *Compression strength(Mp)* | *Frequency* | *Statistical probability* |
|---|---|---|
| 2 | 1 | 0.0167 |
| 3 | 2 | 0.0333 |
| 4 | 10 | 0.1667 |
| 5 | 22 | 0.3667 |
| 6 | 10 | 0.1667 |
| 7 | 6 | 0.1 |
| 8 | 3 | 0.05 |
| 9 | 3 | 0.05 |
| 10 | 3 | 0.05 |




(a)Crushing Value

(b)Water Absorption

(c)Apparent Density

(d)Mud Content

Figure 1. Curve of performance of recycled aggregate and its size and original concrete strength

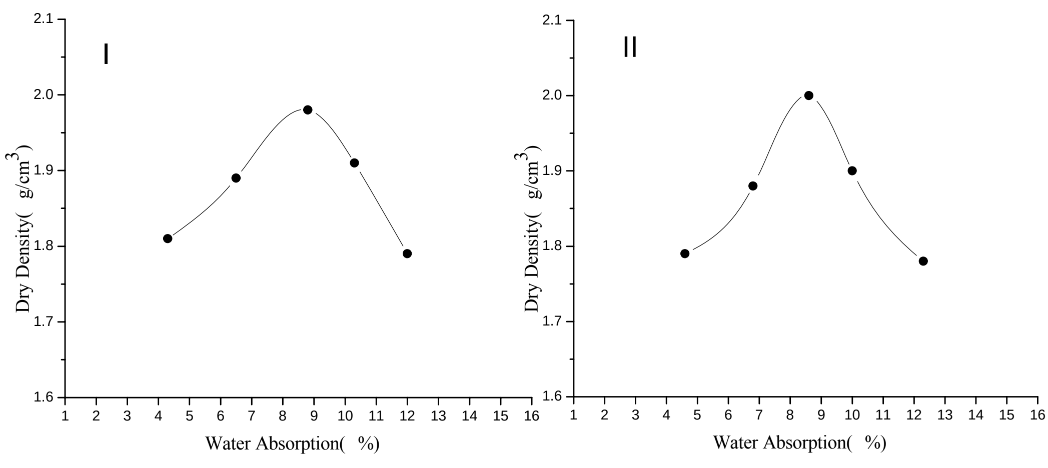



Figure 2. Moisture content - dry density curve of recycled Subgrade material

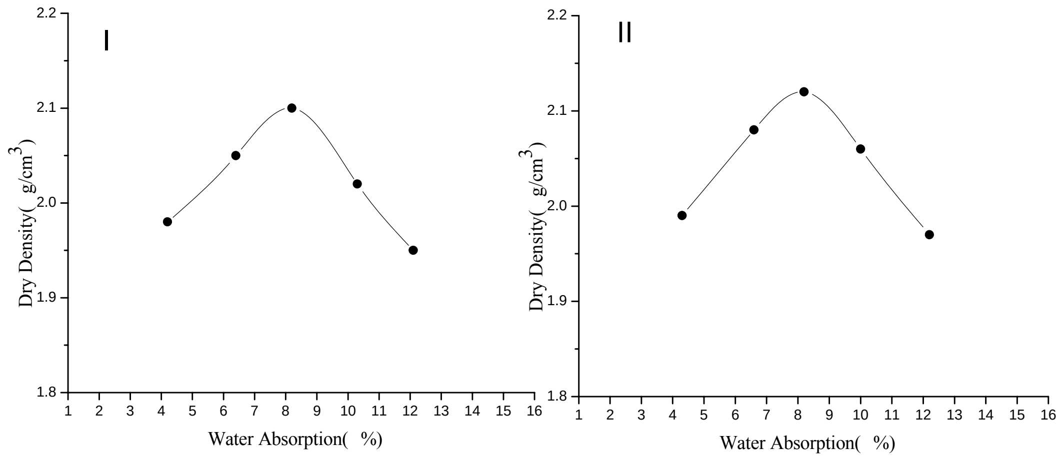
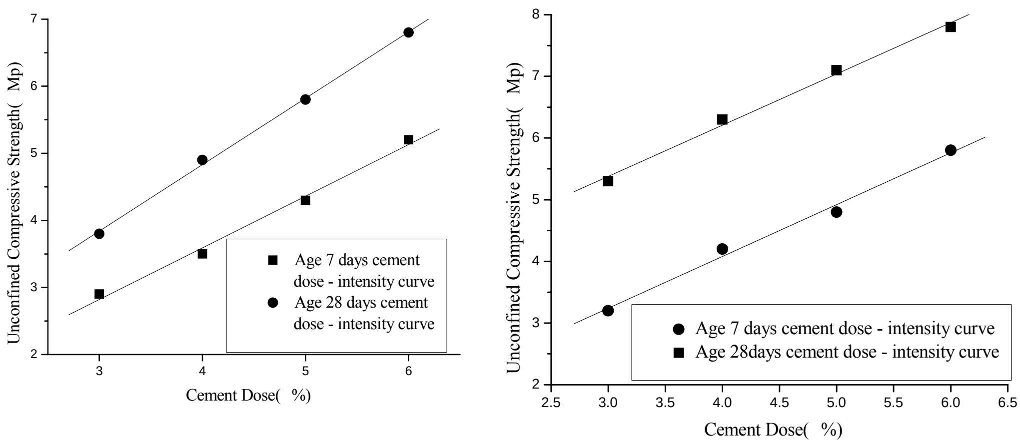
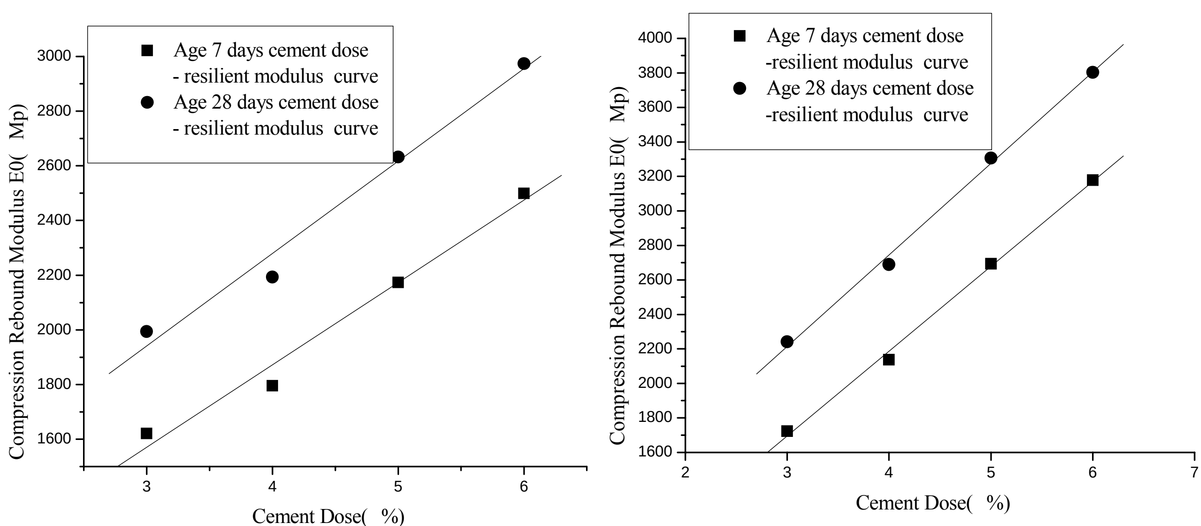



Figure 3. Moisture content - dry density curve of recycled base material



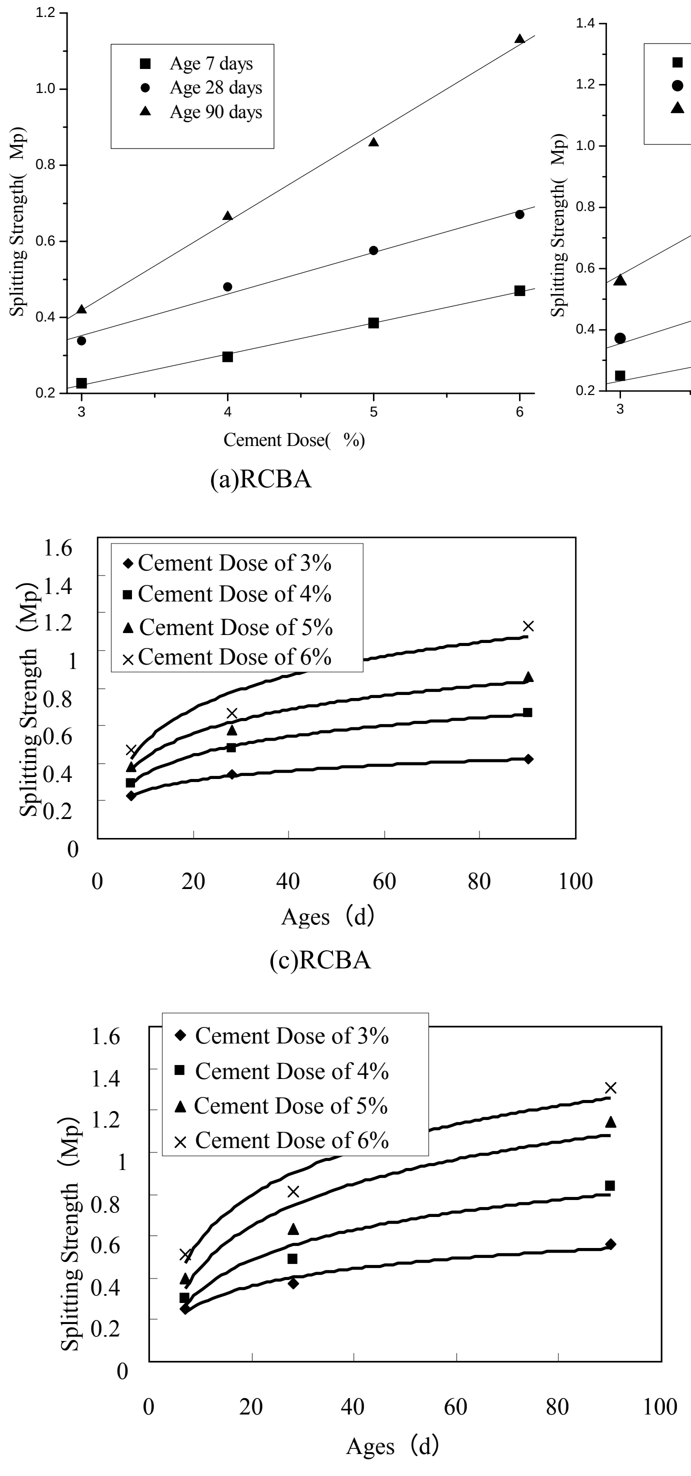

(a)RCBA (b)RCA

Figure 4. Linear regression trend intensity growth of recycled road materials




(a)RCBA (b)RCA

Figure 5. Linear regression trend resilient modulus growth of recycled road materials




(a)RCBA (b)RCA

(c)RCBA

(d)RCA

Figure 6. The growth trend of recycled road materials

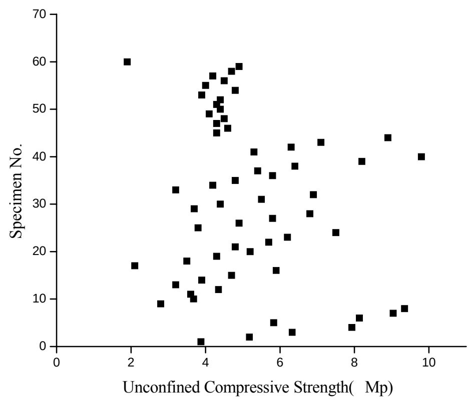



Figure 7. Scattergram of unconfined compression strength test

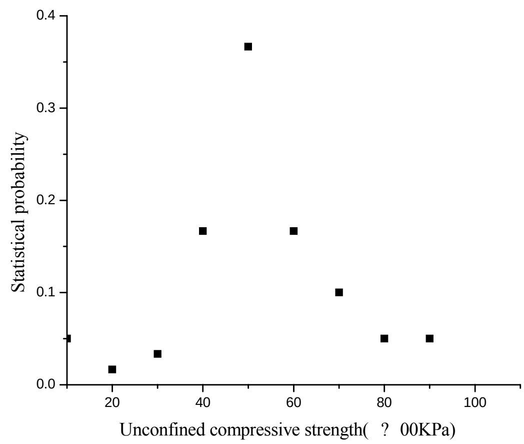



Figure 8. Extreme value distribution of unconfined compression strength test

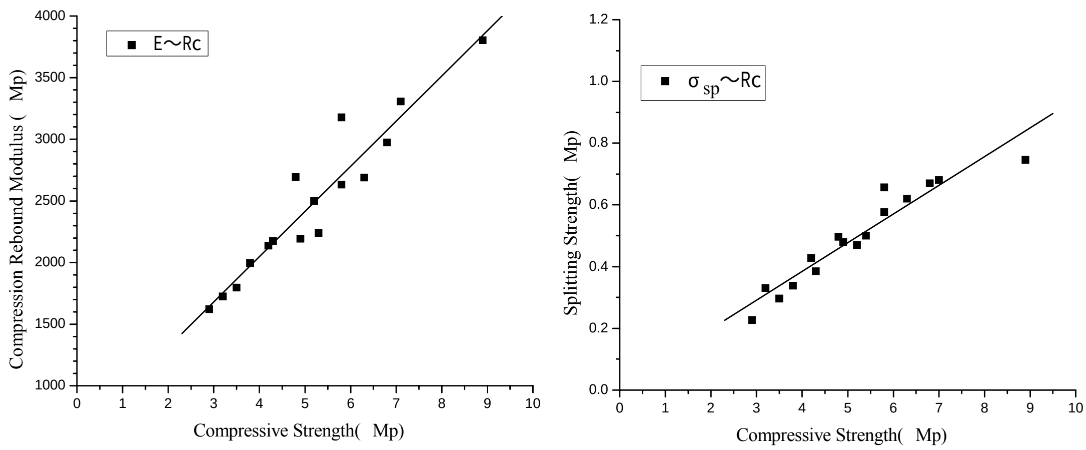



Figure 9. Regression relationship between compressive strength and modulus rebound, spilt intensity