



CRUSHED WASTE CONCRETE IN STONE MASTIC ASPHALT MIXTURES

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Abstract. The magnitude 7.6 Chi-Chi Taiwan in 1999 and the magnitude 7.9 Sichuan China in 2008 earthquakes caused many building damage and collapse, and a large amount of waste concrete caused many environmental problems. This study evaluates crushed waste concrete used as aggregate for stone mastic asphalt. On the basis of this study, the ANOVA of the permanent deformation test shows that the type of aggregate has a significant effect at test temperature of 60 °C, but not significantly affect at 25 °C. Thus, the ability of permanent deformation resistance of the crushed waste concrete mixture is better than that of 100% virgin crush stone mixture. The stability values of the crushed waste concrete mixtures are higher than the 100% crush stone mixture, especially in 50% crushed waste concrete plus 50% crush stone and coarse crush stone plus fine crushed waste concrete (C-crush stone plus F-crushed waste concrete). The stone mastic asphalt mixed with 50% crushed waste concrete plus 50% crush stone are more practicable for use than others.

Keywords: crushed waste concrete (CWC), stone mastic asphalt (SMA), resilient modulus, permanent deformation.

1. Introduction

Due to 921 Chi-Chi Taiwan strong earthquake which caused many building damage and collapse in 1999, a large amount of waste concrete was demolished to the scrap heap and caused many environmental problems in this small island. In accordance with the statistical data report from the Ministry of the Interior, about 1 million cubic meters of waste concrete are produced every year in Taiwan. How to deal with the waste materials has become an environmental problem in a small island of Taiwan. The disposal of waste products primarily has three ways to deal with such as landfills, incineration and recycling. However, landfills are not suitable in Taiwan right now because of the large number of population living in such a small island so that there is no extra space for them. In addition, the waste building materials cannot be incinerated (Shen, Du 2004). Thus, one of the ways to reduce is crushed and recycled. The properties of the crushed waste concrete (CWC) have more impure materials, fracture and rough faces than general aggregates have (Shen, Du 2004, 2005).

Stone mastic asphalt (SMA) concrete composed of crushed coarse and fine aggregate, mineral filler, asphalt cement, and stabilizing agent is designed to have higher contents of coarse aggregate (70–80% by weight), asphalt (over 6% by weight) and filler (8–13% by weight) than normal hot mix asphalt has (Radziszewski 2007; Roberts *et al.* 1996; Sivilevičius 2002; Vislavičius 2002). Specially, the high coarse aggregate contents in stone on stone contact produce highly resistance to rutting (Radziszewski 2007; Shen, Du 2005; Sivilevičius, Petkevičius 2002). Interlocking makes the aggregates difficult to displacement by compaction. Sand particles within the aggregate gradation, contacts disappear between stone particles, so interlocking of stone particles is weak (Haryanto, Takahashi 2007). The crushed waste concrete (CWC) used as aggregate in stone mastic asphalt (SMA) mixture can also provide more shear strength resistance than general asphalt mixtures do; and the probability of shear strains in asphalt concrete is higher when the pavement temperature is high (Laurinavičius, Čygas 2003). Thus, SMA with CWC increasing the stress resistance of asphalt concrete could solve the problem. In

addition, the mixture is new and its engineering properties and performance need to be evaluated. Thus, in order to reduce waste concrete, an investigation of the CWC recycled as an aggregate and replaced all or part of the virgin aggregate for SMA mixtures was carried out.

Asphalt pavement in actual circumstances is subjected to the repetitive and changing transport load. As a result of the repetitive load impact, both elastic and plastic deformations occur to the pavement. Accumulation of plastic deformations in one or several layers leads to appearance of permanent deformations or rutting. This type of deformations reduces safety and convenience of traffic (Haritonovs *et al.* 2010). The binder of modified asphalt was used for the Marshall mix design; and permanent deformation and resilient modulus test were carried out.

2. Plan of study

The performance of laboratory compacted SMA mixtures were as follows:

- 100% virgin crush stone (CS) (100% CS);
- 100% CWC;
- 50% coarse and fine CWC plus 50% coarse and fine CS (50% CWC plus 50% CS);
- coarse CWC plus fine CS (C-CWC plus F-CS);
- coarse CS plus fine CWC (C-CS plus F-CWC), mixed with modified asphalt cement.

Permanent deformation and resilient modulus test were used for determining the laboratory performance of the CWC mixtures. Based on the laboratory tests, the ANOVA analysis was used to evaluate the significant effects and to determine the best mix proportions based on laboratory performance.

3. Laboratory evaluation

3.1. Aggregate, binder and gradation

The CWC used as aggregate was obtained from Sindian City, Taiwan. CS was obtained from local quarry field. The hydrated lime as a mineral filler was from a commercial source. The properties of CWC and CS aggregate are shown in Table 1. Processed CWC aggregate has higher angular, rougher surface texture, lower specific gravity, higher Los Angeles abrasion, higher sodium soundness, and higher water absorption than the CS.

Polymer modified asphalt cement shown in Table 2 was from local petroleum company. The aggregate gradation used throughout the study shown in Table 3 was developed in accordance with *ASTM D3515-01 Standard Specification for Hot-Mixed, Hot-Laid Bituminous Paving Mixtures (ASTM D3515)*. Lime used as filler is applied instead of the aggregates passing No. 200 sieve (0.075 mm).

3.2. Mix design

SMA mix design was performed following the Marshall method in accordance with *ASTM D1559 Test Method for Resistance of Plastic Flow of Bituminous Mixtures Using Marshall Apparatus*. 18 batching samples of SMA mixed with varied asphalt contents in 0.5% increment were heat-

Table 1. The properties of CWC and CS

| Property | Specification | CS | CWC |
|---------------------------------|---------------|-------|-------|
| Bulk specific gravity, coarse | – | 2.655 | 2.273 |
| Bulk specific gravity, fine | – | 2.516 | 2.261 |
| Absorption, % | – | 0.600 | 6.1 |
| Unit weight, kg/cm ³ | – | 2012 | 1503 |
| Los Angeles abrasion, % | < 40 | 20.20 | 40.7 |
| Sodium soundness (5 cycles), % | < 12 | 9.220 | 52.2 |
| Elongated, % | > 0.67 | 0.690 | 0.71 |
| Flat, % | > 0.67 | 0.680 | 0.69 |
| Rounded index | – | 0.520 | 0.61 |
| Shape factor, % | – | 0.53 | 0.57 |

Table 2. The properties of modified asphalt cement

| Property | Specification | Testing |
|---|---------------|---------|
| Penetration, 1/100 cm | > 50 | 55.2 |
| Specific gravity, 25 °C | – | 1.028 |
| Softening point, °C | – | 50.5 |
| Ductility, kgf-cm, 25°C | – | 97.9 |
| Viscosity, 60 °C, poise | > 4500 | 7255 |
| Viscosity, 135 °C, cst | < 3000 | 2365 |
| Penetration, 25 °C, 100 g, 5 s, 1/100 cm | > 50 | 55.2 |
| Penetration, 40 °C, 200 g, 60 s, 1/100 cm | > 10 | 23.1 |

Table 3. Aggregate gradation

| Sieves | SMA 12.5 mm | SMA | Testing |
|--------------------|----------------------|-------|---------|
| 19 mm | 100 | 100 | 100 |
| 12.5 mm | 90–100 | 85–95 | 92.5 |
| 9.5 mm | 40–60 | < 75 | 50 |
| No. 4 | 20–35 | 20–28 | 24 |
| No. 8 | 15–25 | 16–24 | 20 |
| No. 30 | – | 12–16 | 14 |
| No. 50 | – | 12–15 | 13.5 |
| No. 200 | 7–12 | 8–10 | 9 |
| Asphalt content, % | 6.5–7.5 | > 6.0 | 6.5–7.5 |
| Fibre content, % | Cellulose fibre 0.3% | | |
| Void, % | 2–4 | | |
| VMA, % | > 17 | | |
| Blows | 50 each side | | |

ed and compacted. All of the samples were compacted by 50 blows per face with the standard Marshall compactor. The Marshall stability and flow were determined by the standard Marshall equipment (Haryanto, Takahashi 2007). The optimum asphalt content (OAC) was determined at

4% air void contents in accordance with the *National Asphalt Pavement Association 1982 Mix Design Techniques – Part I. Instructors Manual*.

3.3. Permanent deformation test

Ruts are treated as dangerous defects, since they might cause danger for traffic, especially when the pavement is wet (Laurinavičius, Oginskas 2006). The permanent deformation test was performed employing the wheel-tracking device following the wheel tracking device testing procedure (Nienelt, Thamfald 1988). The facility was developed by the Swiss and modified by the University of Hokkaido, Japan. The samples, mixed with optimum asphalt contents from Marshall mix design and fabricated by the rolling machine were 300×300 mm in section area and 50 mm in height. The test was performed using 2.18 MPa wheel load at test temperatures of 25±10 °C and 60±1 °C for dry condition. The depth of deformation was measured at 100, 200, 400, 800, 1400, 1890 and 2520 cycles.

3.4. Resilient modulus test

The resilient modulus (M_R) test, following *ASTM D4123 Standard Test Method for Indirect Tension Test for Resilient Modulus of Bituminous Mixtures*, is the most common method of measuring stiffness modulus for hot mixture asphalt. All tests were conducted on triplicate samples at test temperatures of 40±1 °C and 25±1 °C. The resilient modulus test was performed after 50 pulse cycles and determined by the following equation:

$$M_R = \frac{P(v+0.27)}{\delta_h h}$$

where M_R – resilient modulus, MPa; P – applied load, kN; v – Poisson's ratio; δ_h – horizontal deformation, cm; h – sample thickness, cm.

4. Results and discussion

The tests described above were conducted, and the data described in the following sections were collected on all samples.

4.1. Marshall design properties

The properties of the SMA mixture specimens are shown in Table 4. In Table 4 all of the stability values of CWC mixtures satisfied with the specification requirements

is greater than 6.24 kN and higher than that of 100% CS mixture. Compared to conventional CS mixtures in terms of the stability and flow values of all types of replacement, the max value of stability and min flow occur in the 100% CWC and C-CS plus F-CWC mixture, respectively. All of the voids in mineral aggregate (VMA) greater than 17% are satisfied with the criteria. However, 100% CWC and C-CWC plus F-CS are not satisfied with flow criteria of the Marshall mix design. As shown in Table 1, the bulk specific gravity of CWC is less than that of CS. This is primary reason that unit weights of all SMA with CWC are less than CS. In addition, CWC aggregate has more angular and rougher surface texture than CS has. Thus, SMA with CWC has higher OAC and higher stability due to increase resistance by aggregate's stone on stone contact (interlocking).

4.2. Permanent deformation

The results of the average deformation of each sample from the tests at 25 and 60 °C are plotted in Figs 1 and 2, respectively. All of the deformations are less than 1.00 mm at 25 °C and 2.50 mm at 60 °C, and the CS has the lowest deformation at test temperature of 25 °C, but the highest deformation at test temperature of 60 °C. In Fig. 2, the 100% CWC and 50% CWC plus 50% CS have the lowest deformation. The deformation at 60 °C indicates that it appears to be plastic flow not densification. Due to the internal friction between aggregate particles providing the ability of deformation resistance, plastic flow can be minimized by using large size aggregate, angular and rough textured coarse and fine aggregates (Roberts *et al.* 1996). Therefore, the smaller observed deformation of the 50% CWC plus 50% CS suggests that these mixes have more angular and rougher particles than that of CS mixture, and thus have higher internal friction.

In general, it is believed that the higher asphalt contents provide higher plastic flow susceptibility. The high plastic susceptibility may lead to high permanent deformation, due to too much asphalt cement in the mix causing loss of internal friction between aggregate particles, which results in the loads being carried by the asphalt cement rather than the aggregate structure. In Table 4, although the CWC mixtures have higher asphalt contents than the CS mixtures, this is not the case for deformation following the preceding description. The phenomenon may be explained by the fact that the high proportion of internal

Table 4. SMA mixture properties at optimum asphalt contents

| Aggregate | OAC, % | | Unit weight, kg/m ³ | Void, % | VMA, % | VFA, % | Stability, kN | Flow, 0.01 cm |
|------------------|---------------------|-----------------|--------------------------------|---------|--------|--------|---------------|---------------|
| | by aggregate weight | by total weight | | | | | | |
| Specification | – | – | – | 2–4 | > 17 | – | > 6.24 | 20–40 |
| CS | 6.10 | 5.75 | 2332 | 4 | 17.00 | 76.3 | 6.45 | 38.0 |
| 100% CWC | 7.65 | 7.11 | 2058 | 4 | 17.40 | 77.0 | 9.95 | 43.9 |
| 50% CWC + 50% CS | 6.50 | 6.10 | 2195 | 4 | 17.40 | 76.0 | 8.15 | 33.8 |
| C-CWC + F-CS | 7.18 | 6.70 | 2069 | 4 | 17.33 | 77.0 | 8.29 | 52.0 |
| C-CS + F-CWC | 6.93 | 6.48 | 2298 | 4 | 18.00 | 78.0 | 6.84 | 32.5 |

friction plays the main role in deformation resistance. To determine the statistical significance of the effect of aggregate type on the wheel load deformation test, a one-way analysis of variance (ANOVA) was performed on the test. The ANOVA was performed to determine whether the treatments were significant at a confidence limit of 95%. Table 5 shows the results of the ANOVA test and indicates that the type of aggregate has a significant effect at temperature of 60 °C, but not a significant effect at temperature of 25 °C. This situation suggests that the angular and rough textured aggregate play the main role in the deformation resistance of SMA at high temperature.

4.3. Resilient modulus

The M_R test results are shown in Fig. 3. As can be seen in Fig. 3, the CS aggregate mixture has the highest M_R values at test temperatures of 25 °C and 40 °C. The 50% CWC + 50% CS and 100% CWC mixtures have a 2nd high M_R values at test temperature of 25 °C and 40 °C, respectively. The high modulus values should provide cost effectiveness and min practical thickness. In addition, M_R values above

Table 5. One way ANOVA test on permanent deformation

| Source of variation | SS | df | MS | F | F _{0.05} |
|----------------------|--------|----|-------|-------|-------------------|
| Temperature at 25 °C | | | | | |
| Types of aggregate | 0.596 | 4 | 0.149 | 2.494 | 2.670 |
| Within | 1.792 | 30 | 0.060 | | |
| Total | 2.388 | 34 | | | |
| Temperature at 60 °C | | | | | |
| Types of aggregate | 3.221 | 4 | 0.805 | 3.547 | 2.690 |
| Within | 6.809 | 30 | 0.227 | | |
| Total | 10.030 | 34 | | | |

3100 MPa (450 000 psi) at 20 °C are stiffer and more resistant to bending according *AASHTO 1993 Guide for Design of Pavement Structures*. However, high values of M_R at low temperatures are somewhat related to cracking (Roberts *et al.* 1996). Fortunately, low temperature cracking never happens in Taiwan due to the high and mild temperatures present the whole year. Thus, the high M_R values of the CWC mixtures provide a good capacity for distress resistance.

5. Conclusions

The data analysis indicates that the performance of SMA with CWC in Taiwan is related to the highly crushed face and high absorption of asphalt cement aggregate. The aggregate contributed to the internal friction for deformation resistance. Based on the results of this study, the following conclusions and recommendations are suggested to improve the performance of SMA with CWC:

- the stability values of the CWC mixtures are higher than the 100% CS mixture, especially in 50% CWC + 50% CS and C-CS + F-CWC;
- the ANOVA of the permanent deformation test shows that the type of aggregate has a significant effect at temperature of 60 °C but not at temperature of 25 °C. Thus, the ability of permanent deformation resistance of the CWC mixture is better than that of 100% CS mixture;
- the SMA mixed with 50% CWC + 50% CS are more practicable for use than others;

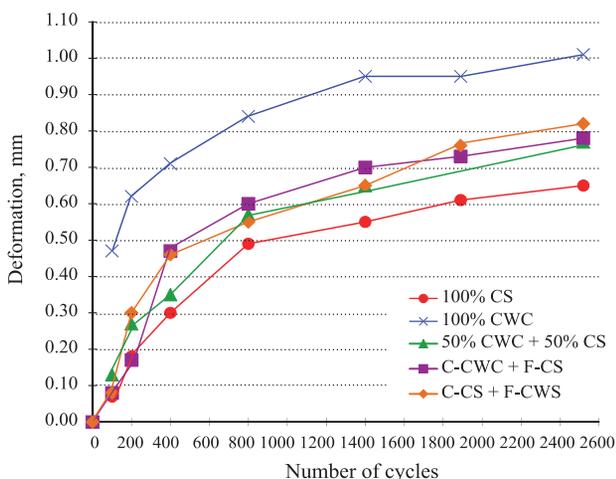


Fig. 1. Rutting test results at 25 °C

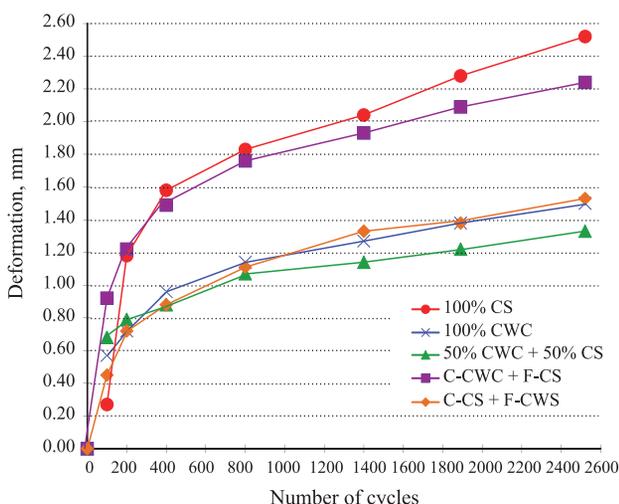


Fig. 2. Rutting test results at 60 °C

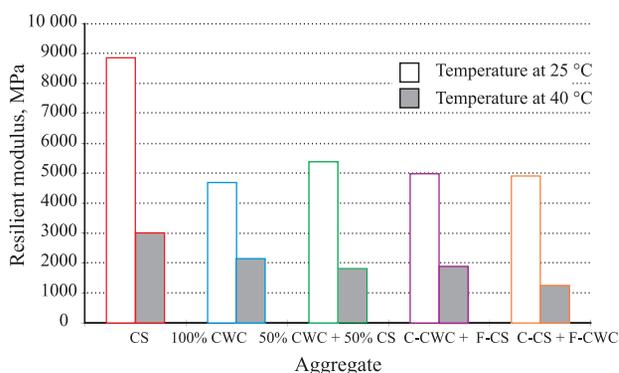


Fig. 3. Resilient modulus test results

- the CWC used as aggregate in SMA mixture can provide better performance than general asphalt mixtures do, and find a way to solve the environment problem related to the large amount of waste concrete.

6. Acknowledge

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