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Evaluation of “long-term behaviour under traffic” of cement treated mixture with RAP

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ABSTRACT

A laboratory investigation was performed to better understand the performance of Cement-Treated Base (CTB) mixtures containing Recycled Asphalt Pavement (RAP) during a long-lasting service period. Two CTB mixtures, one containing only virgin aggregates and the other containing RAP and virgin aggregates, were tested by triaxial tests (static and cyclic) and resonant column tests to evaluate stiffness and dampening at very small deformations. Similar mechanical properties and response to cyclic loadings were obtained for the two mixtures. The results led to the conclusion that the use of RAP as a replacement for virgin aggregates for a CTB mixture does not cause any significant alteration in terms of mechanical performance.

Keywords: Reclaimed Asphalt Pavement (RAP), Cement-Treated Base (CTB) mixtures, long-term behaviour, Triaxial Test, Resonant Column Test, Shear Modulus, Damping, Friction Angle, Cohesiveness.

1. Introduction

In the last two decades, the use of recycled materials from milled asphalt pavements in road maintenance and rehabilitation has become increasingly popular. Many government agencies have recently promoted the use of Recycled Asphalt Pavement (RAP) to reduce both the environmental impact caused by the use of natural resources and their transport, and the costs of maintenance operations. More commonly, RAP is used as an aggregate for the production of new mixtures, but it must be considered that there are pavements that exhibit more severe structural problems requiring radical and deeper interventions up to the modification of the base layer. To this purpose, it is possible to operate recycling the base layer with the addition of a suitable stabilizing agent, such as cement, that may increase the mechanical properties of the same layer.

Numerous researches have been performed to investigate the mechanical behavior of Cement-Treated Base (CTB) mixtures containing RAP and to better investigate which variables influence them most. Yuan et al. [1] investigated how the strength/modulus of CTB-RAP mixtures varies according to the RAP and cement content, showing how the Unconfined Compressive Strength (UCS) is directly proportional to the added cement content, and the optimum percentage of cement increases with the increase of the RAP content. Puppala et al. [2] studied the variation of the resilient modulus in CTB-RAP mixes with the variation of the cement quantity and found an increase of the resilient modulus with the increase of the cement content in the mix. A study conducted by Yang and Wu [3] showed that by increasing the amount of RAP in the mixture, the UCS initially rises and then decreases to a certain percentage of recycled material. They also showed how, by using high percentages of cement, the UCS decreases as the RAP content increases. Khay et al. [4] studied the mixture keeping the percentage of cement constant and increasing the amount of RAP finding that the UCS of the mixture decreases as the amount of RAP increases.

What has been found, so far, shows that CTB-RAP mixtures seem to have good mechanical properties to address structural problems of flexible pavements during maintenance. At the moment, however, the long-term behavior of these mixtures is still not clear. Isola et al. [5] developed a full scale test track to evaluate, under real traffic condition, the use of RAP in CTB mixtures. The pavement performance were tested using non destructive devices (i.e. Light Weight Deflectometer, Falling Weight Deflectometer and Ground Penetrating Radar). After 15 month of continuous monitoring, no clear deterioration due to traffic was either visibly and on FWD results.

This paper presents a laboratory investigation performed to better understand the performance of CTB mixtures containing RAP during a long-lasting service period.

Two CTB mixtures, one containing only virgin aggregates and the other containing RAP and virgin aggregates, were tested by triaxial tests (static and cyclic) and resonant column tests to evaluate stiffness and dampening at very small deformations. The main purpose of this research work it is to investigate the behavior of a CTB-RAP mixture close to failure due to a long series of cyclic loadings. The final objective is to better understand how the presence of this material can influence the long-term behavior of a flexible pavement and to verify if the presence of cement can cause a brittle failure.

2. Materials and Mix Design

Two different CTB mixtures, one composed only by virgin aggregates and the other composed by RAP and virgin aggregates were investigated in this study.

Only the RAP clusters passing the sieve #30-40 were employed since it was observed that the clusters with higher dimensions could be broken during compaction, leading to a total modified gradation of the mixture. This decision was conceived on the base of the theoretical approach developed by Roque et al. [6], named Dominant Aggregate Size Ratio–Interstitial Component. According to this framework, aggregates can be divided in a primary structure, named Dominant Aggregate Size Ratio (DASR) and a secondary structure Interstitial Component (IC), which forms the mixture lithic structure. Figure 1 shows the structure of the material: the DASR is represented by the aggregates while the interstitial mixture is the matrix with the interstitial components.

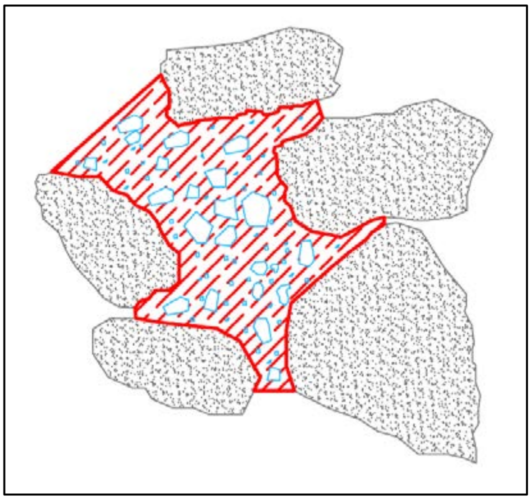

Figure 1: IC mixture affecting mixture behaviour.

Recent studies [7, 8, 9], have shown that IC in the asphalt mixture is a key component that most affects the mixture overall behavior. Indeed, micro-damage accumulation is localized in IC mixtures causing fatigue damage accumulation. Since the RAP can be considered some kind of asphalt mixture, it was decided to use only the finest part of the aggregate, assuming that the long-term behavior of the mixtures is closely dependent on the mechanical properties of the IC. Regarding the CTB composed of virgin aggregates, the assumption to consider only the class passing the sieve #30-40 means to analyze the matrix that wraps the coarser aggregates. This assumption has also the not negligible advantage to allow the use of small size specimens for triaxial test avoiding problems related to size effects.

The two different mixtures were designed and selected to obtain comparable lithic structures. One source of RAP was employed, after being sieved according to UNI dimensions. The virgin aggregates have sandstone origin with the following properties: 22% of Los Angeles, 15% of Micro-Deval, 65% sand equivalent. The gradations of CTB mixtures are shown in Figure 2.

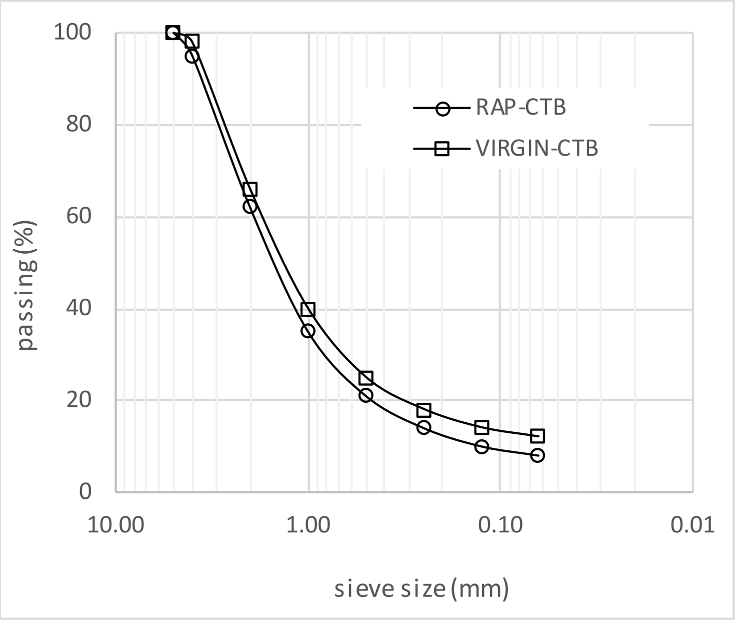

Figure 2: Aggregate gradation of the two CTB mixtures

The mixtures were prepared using a water-cement ratio of 2, using the 3% of the cement by the aggregates weight and were mixed according to the optimum moisture content. The cylindrical specimens, 50 mm diameter and 100 mm high, were prepared by static compaction in order to obtain a density corresponding the modified compaction one (Modified Proctor). The specimens were then cured for 3 months in a moist chamber at 25°C. Figure 3 shows the final specimens.

Figure 3: RAP-CBT specimen on the left, Virgin-CBT specimen on the right

3. Experimental Methods

Different equipment and methodologies were employed to better understand the performance of CTB mixtures containing RAP during a long-lasting service period:

3.1 Consolidated-Drained (CD) Triaxial Compression Test

This test is used to determine the fracture resistance parameters. The test consists of bringing to fracture an isotropically consolidated cylindrical specimen by increasing the deviatoric stress. Four different confining pressures were applied to calculate the failure envelope: 25kPa, 50kPa, 100kPa and 200kPa. A very low deformation speed is assured in order not to create interstitial overpressure. Essentially, the Effective Stress corresponds to the Total Stress (u=0). The reference standard is UNI EN ISO 17892-9:2018 [10]

3.2 Cyclic Triaxial Test

The equipment is basically the same as the static triaxial tests except for the loading press. The system for the application of the cyclic load is electropneumatic, composed of a function generator, a proportional pressure regulator and a pneumatic cylinder (actuator). The cylindrical specimens were tested in a load control mode applying a sinusoidal load wave of 1MP and a deviatoric stress of 1MPa, with a frequency of 1Hz for 1000 cycles at 20 ± 0.5°C. The confinement pressure is 25kPa. The reference standard is UNI EN 12697-25:2016 [11]

Cyclic Triaxial Tests were performed to simulate long-lasting fatigue damage. The test configuration is shown in Figure 4. A repeated sinusoidal loading at a frequency of 1 Hz has been applied for a number of cycles equal to 10000. The force control mode has been employed, applying a deviatoric stress of 1MPa.

Figure 4: Cyclic Triaxial Test Configuration

Figure 5 shows deviatoric stress, axial strain during load cycles and the hysteresis cycle. This test setup was selected to create in the material the same stress and strain distribution caused by the traffic load.

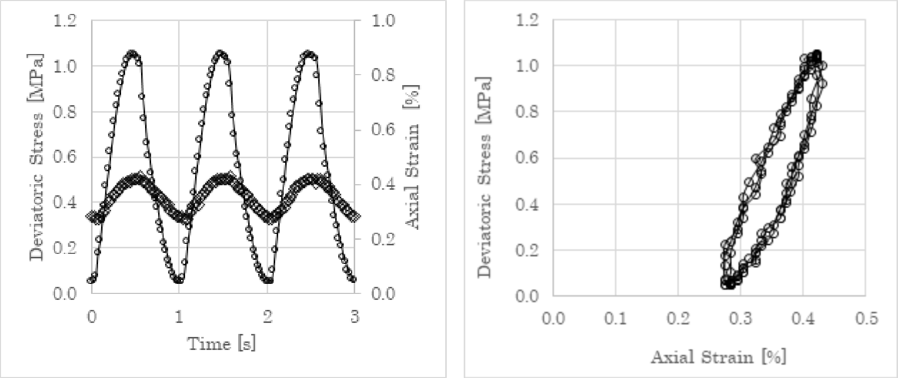

Figure 5: Left: Deviatoric stress and axial strain during loading cycles; Right: Hysteresis cycle

3.3 Resonant Column Test

This equipment allows evaluating stiffness and damping at very small deformations (10-4%), when the material is behaving elastically. The specimen is cylindrical and isotropically consolidated, similarly to conventional triaxial tests. From a sinusoidal electrical signal generated by a function generator, a mechanical torsional stress is obtained by means of an electromagnetic engine consisting of eight coils that interact with four permanent magnets attached to the head of the specimen. The mechanical response is measured by means of an accelerometer attached to the specimen head and connected to an oscilloscope. The test configuration is shown in Figure 6.

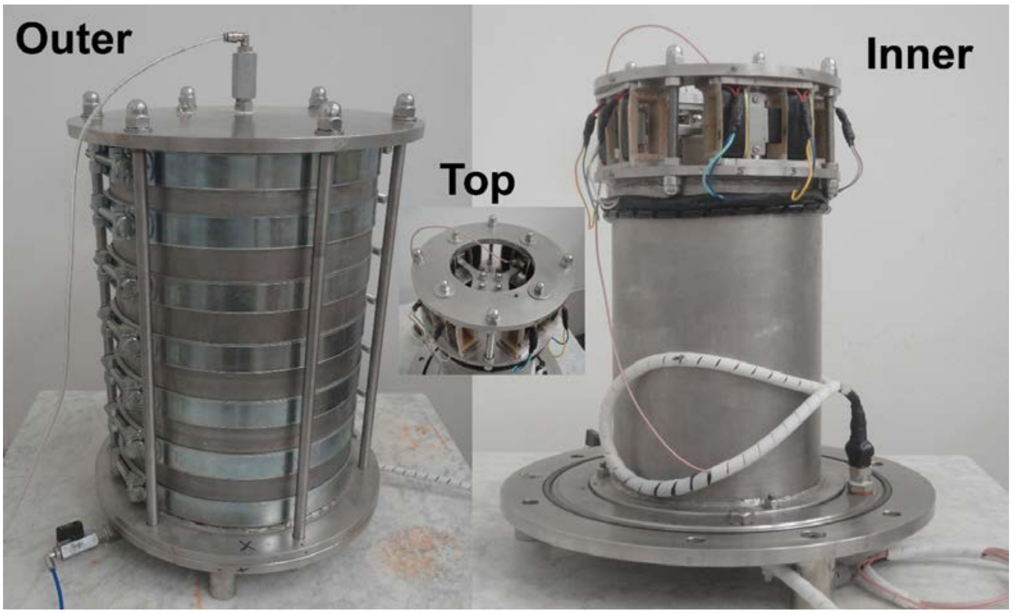

Figure 6: Resonant Column Test Configuration

The excitation frequency is varied until the resonance condition is reached. Under resonance conditions, given the resonance and the height of the specimen, it is possible to calculate the propagation speed of the shear waves (V_s). Given the density of the specimen (ρ), the stiffness, in terms of shear modulus, can be obtained:

$$G = \rho \cdot V_s^2 \qquad [1]$$

The Damping ratio D can be determined by interrupting the excitation and measuring the decay of the free oscillations:

$$D = \sqrt{\frac{\delta^2}{4\pi^2+\delta^2}} \qquad [2]$$

where δ is the logarithmic decrement of vibration, measured at the top of the specimen.

The operating frequencies are in the order of tens of Hz, but can also exceed 100 Hz. The reference standard is ASTM D4015 [12].

4. Experimental Investigation

The experimental investigation involved a sequence of tests specifically planned in series to achieve an overall understanding of the long-term performance of CTB mixtures containing RAP.

Firstly, preliminary tests were performed to understand the initial parameters of undamaged materials. Triaxial CD tests were conducted to determine shear strength parameters at confinement pressures of 25kPa, 50kPa, 100kPa and 200kPa. Then, resonant column tests were performed to determine elastic shear and damping modulus at 25kPa confinement pressure. Later on, triaxial cyclic tests were carried out for each material to determine the evolution of permanent deformation and resilient modulus during the application of load cycles up to 10000 cycles, imposing a confinement pressure of 25kPa. At the end of the trial session, the same specimens, apparently undamaged, were brought to rupture by triaxial CD tests imposing successive confinement pressures (25kPa, 50kPa, 100kPa and 200kPa) to evaluate the effect of cyclic stress on the resistance parameters. This procedure was selected because it was not possible to achieve specimen failure by the simple application of cyclic loading. It was not desirable to increase the load, as this would have excessively modified the real material conditions within the pavement.

After this first series of tests, a new testing session was conducted, consisting in loading new specimens to cyclic stress for 5000 cycles, with a confinement pressure of 25kPa. At the end of the 5000 cycles, the same specimens were tested with CD triaxial tests imposing confinement pressures of 25 and 100 kPa.

The last series of tests consisted in loading the specimens up to 10000 cycles with a confinement pressure of 25kPa, while measuring the speed of wave propagation (Vp) every 2000 cycles.

5. Results and Discussion

Preliminary test results are listed in Table 1, indicating that mixtures containing RAP show significantly less decay than those consisting of only virgin materials.

Table 1. Parameters of undamaged materials

Mixture ID	Denstiy (Mg/m^3)	Shear Modulus (GPa)	Damping (%)	Cohesion (kPa)	Angle of Shear Resistance (°)
CTB-RAP	2.00	1.30	5.2	423	37.3
CTB-VIRG	2.20	2.62	3.3	637	42.2

This is clearly visible in Figure 7 where the fracture envelopes are compared before and after 10000 load cycles application for both mixtures. It can be observed that the decay of CTB-VIRGIN mixtures is around 30% compared to 20% of that experienced by CTB-RAP mixtures. Moreover, it was observed that 5000 load cycles had no fundamental impacts on the fracture envelopes leading to the conclusion that the greatest decay occurs abruptly after exceeding half of the design life.

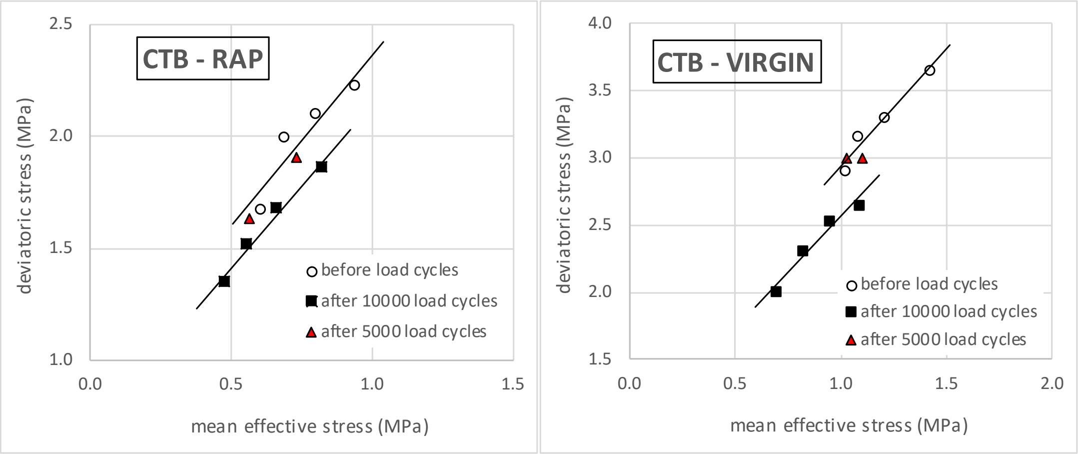

Figure 7. Comparison between failure envelop curves before loading, after 5000 loading cycles and after 10000 loading cycles for both mixtures.

This is more confirmed by the Resilient Modulus results obtained during the first trial of tests performed with triaxial cyclic test and, above all, by the results related to the wave propagation speed obtained from the last series of tests (Figure 8). In both cases, it can be observed that the major damage to the materials occurs around the achievement of 8000 cycles.

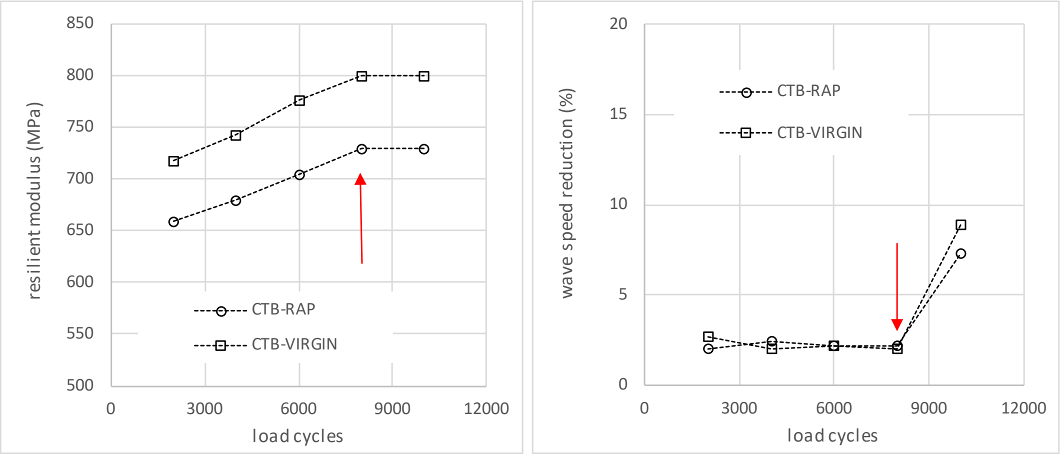

Figure 8. Resilient Modulus and Wave Speed Reduction during cyclic loading

From the other side, the accumulation of permanent deformations (Figure 9) shows that CTB-Virgin has much more rigid behaviour than CTB-RAP: CTB-RAP has almost 3-time higher value of permanent deformation under cyclic load and it has 2.5-higher deformation increasing rate than CTB-Virgin.

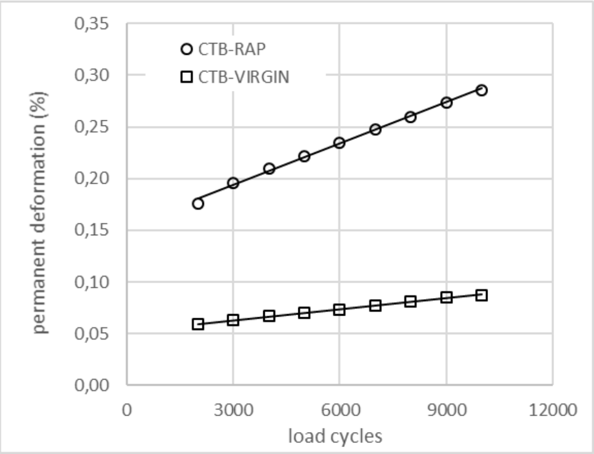

Figure 9. Comparison between accumulation of permanent deformation of CTB-RAP and CTB-virgin

6. Summary and Conclusions

The experimental investigation presented in this paper evaluated the performance of two cement treated mixtures: one composed of virgin aggregates and one composed of reclaimed asphalt. Specimens of both mixtures were tested using a triaxial configuration, applying a confinement pressure and an axial load representative of the real material condition in a pavement layer. Since failure was not reachable at that load level, the material properties after 10000 load cycles were considered.

The two mixtures have shown similar mechanical properties as well as comparable behaviours under cyclic load: both materials have endured the same number of load repetitions without showing any apparent damage. Same consideration can be deduced from the evolution of the resilient modulus and from the wave speed reduction during cyclic loading. Both CTB-Virgin and CTB-RAP showed an increase in the Resilient Modulus to a certain value, after which the modulus remained constant. This behaviour is compatible with the hypothesis that the material undergoes a compaction by cyclic load, up to a limit condition that can be assumed as a condition of stability until the beginning of the failure process. Analysing the evolution of the reduction of the wave speed, it can be seen that the two materials show the same values and the same overall behaviour. This result confirms the hypothesis of the existence of a limit threshold that controls the behaviour of the material. It should also be noted that this threshold corresponds to the same one for which the Resilient Modulus stabilizes, that is about 8000 cycles.

The results obtained in this experimental research support the results obtained by Isola et al. [5] on the full scale test track according to which, after 15 months of opening to traffic, no damage was found, either visible or through FWD analysis.

Observing the comparison between the two failure envelopes before loading, after 5000 and 10000 loading cycles in both cases there is almost no weakening of the materials after 5000 cycles and a reduction of the deviatoric stress after 10000 cycles. The only real difference in the behaviour of the two materials is the extent of the difference between the deviating force before loading and after 10000 cycles: the decrease is much higher in the mixture with virgin aggregates than in that with RAP.

In the mixture composed of virgin aggregates, the bond between the aggregates is provided only by cement, which confers a brittle behaviour with a rapid growth of the damage. In the mixture composed of RAP, the layer of old bitumen that surrounds the aggregates is bonded with the layer of cemented binder forming a sandwich structure (a cement element between the bituminous elements). The structural contribution of the bituminous layers leads to a slow-growth of the damage with a more ductile failure. This hypothesis is supported by the greater stiffness of the CTB-Virgin compared to the CTB-RAP, which was observed by comparing the accumulation of permanent deformations under cyclic load.

In summary, the main results obtained were as follows:

- CTB-RAP and CTB-Virgin have the same ability to withstand a large number of cyclic loading applications;
- CTB-RAP has a slightly lower mechanical strength than CTB-Virgin.
- CTB-Virgin has a much more rigid behaviour than CTB-RAP.
- The CTB-Virgin has a faster damage growth than the CTB-RAP.

Thus, it can be concluded that the use of RAP as a replacement for virgin aggregates for a cement treated base mixture does not cause any significant alteration in terms of mechanical performance.

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