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Mechanical properties of Cold Recycled Bituminous Mixes with Crumb Rubber

Andrea Castro ¹, Jaime Preciado ¹, Gilberto Martinez-Arguelles ¹, Luis Fuentes ¹,
Margareth Dugarte ¹

¹ Universidad del Norte, km 5 vía Puerto Colombia, Barranquilla, Colombia

garguelles@uninorte.edu.co

Abstract. Cold mix recycling technologies based on asphalt emulsion have been acknowledged for allowing to reduce the environmental burdens associated with road pavement maintenance and rehabilitation. In fact, mixing and placement are conducted at lower temperatures leading to energy savings, a reduction of asphalt aging, fume and odour releasing, and a general decrease of airborne emissions. However, there are still several concerns related to the high variability of reclaimed asphalt pavement (RAP), the lack of standard mix-design procedures and the fair/low mechanical performance often achieved especially due to poor moisture resistance. On other side, the addition of crumb rubber into hot mix asphalts is considered an environmentally-friendly and cost-effective practice in several countries. Producing bituminous cold mixes containing crumb rubber to develop a “greener” paving material with a performance level comparable to that of conventional materials, represents a great challenge to materials engineering. This paper presents the results of a laboratory investigation concerning the mix-design characteristics of cold 100%-recycled asphalt emulsion mixes, using crumb rubber to improve cold recycling engineered properties. Mechanical and volumetric properties were assessed through dynamic modulus and indirect tensile strength on dry and water-conditioned specimens.

1. Introduction

The growing interest to diminish the environmental impacts associated with construction, operation and maintenance of the highway infrastructure network, has led pavement community in general to investigate strategies to include waste materials into asphalt mixes. In fact, the incorporation of recycled materials, such as reclaimed asphalt pavement (RAP) and crumb rubber (CR) in hot-asphalt mixes (HMA) is considered an environmental-friendly and an economic-effective practice. Recycling, not only preserve the sources of virgin materials and contributes to the reduction of wasted material stocking (e.g., discarded tires), but also reduces the costs of road pavement construction and maintenance activities [1-3].

Giving the elastic properties of crumb rubber, investigations addressing the inclusion of crumb rubber in asphalt mixes to enhance their performance has received a considerable attention throughout the evolution of paving technologies. In particular, some topics have been studied in the recent years that include: (a) the process of addition of crumb rubber [4,5], (b) the influence of the crumb rubber gradation [2], (c) the influence of crumb rubber on the moisture susceptibility [6,7], (d) the effect of the crumb rubber on the indirect tensile strength and stiffness modulus [2,8,9], among others. However, limited research efforts have been done considering the effects of crumb rubber in Cold Recycled Emulsion Mixes (CREM).



Based on the facts mentioned above and taking in consideration the effects and impacts of HMA production and placement on the environment and the health of construction crews, this paper aimed to determine the feasibility of incorporating crumb rubber in CREM with RAP as 100% of the aggregates in the mix. The study considers four mixes containing 0, 0.25, 0.50 and 0.75% of crumb rubber with an optimum dosage of bitumen emulsion and a fixed dosage of Portland cement (1% by aggregate weight). In order to assess the mechanical performance of the mixes, laboratory tests were conducted including stiffness modulus (ITSM), indirect tensile strength (ITS) and volumetric properties.

2. Objective and scope

The paper presents the results of a laboratory investigation concerning the effect of crumb rubber on the mechanical properties of CREM. The research work has the following objectives:

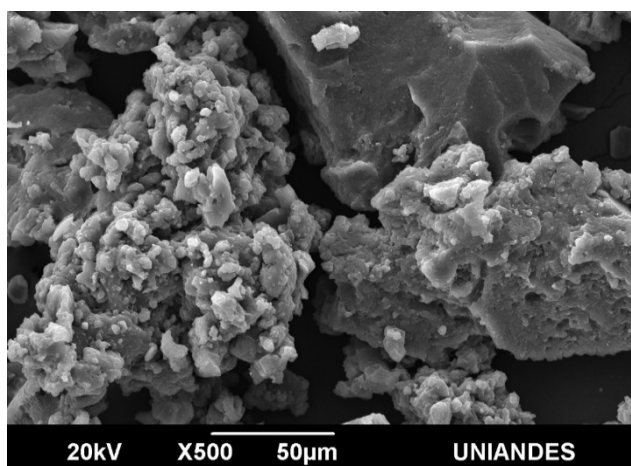
- To analyse the feasibility of using CR on CREM.
- To study the effect of different CR contents on the mechanical properties through the indirect tensile strength (wet and dry condition), Indirect Tensile Stiffness Modulus.
- To evaluate the effect of the addition of CR on the volumetric properties.

3. Materials and experimental program

In this section, the properties of the materials used in this study (crumb rubber, RAP and bitumen emulsion), mix design considerations, specimen preparation and the test procedures are

3.1. Materials

3.1.1. Crumb Rubber Characterization. The crumb rubber used in this study exhibits a granular shaped with a maximum nominal size of 0.425 mm, and mostly composed of CaCO_3 (81.47%). The chemical composition was obtained from an elemental analysis through scanning electron microscopy techniques (SEM). This test is complemented by an X-ray dispersive energy detector (EDS) that detects the X-rays generated in the sample and allows a spectrographic analysis of the elemental composition on its surface of an area or a point (heavy and light elements from Carbon). The gradation of the crumb rubber obtained from sieve analysis is displayed in Figure 2(b) and chemical composition is displayed in Figure 1.



Chemical composition of crumb rubber		
Components		%
C	CaCO_3	81.47
O	SiO_2	9.00
Al	Al_2O_3	0.78
Si	SiO_2	1.21
S	FeS_2	2.34
Ca	CaSiO_3	0.58
Fe		2.21
Zn		2.4
Total		99.99

Figure 1. SEM micrograph of crumb rubber and its chemical composition.

3.1.2. Reclaimed Asphalt Pavement Properties. The RAP was collected from a highway pavement in Barranquilla, Colombia. The material was divided into three fractions (19.0 - 12.7 mm, 12.7 - 4.75 mm, 4.75 - 0 mm), following recommendations for cold bituminous mixes as established in the Cold Recycling Technology Manual (Wirtgen 2012). The gradation analysis indicated that RAP material exhibited practically no fine aggregates. In order to meet the Colombian Standard INV.E No. 461(INVIAS), a second gradation was prepared with the addition of 5% of inert filler to comply with the 100:5 (by mass) RAP plus filler gradation. The particle size distribution of RAP is shown in Figure 2 (a). The RAP has a residual bitumen content of 5.6%, a bulk specific gravity (G_{sb}) of 2.72 and absorption of 1.3%.

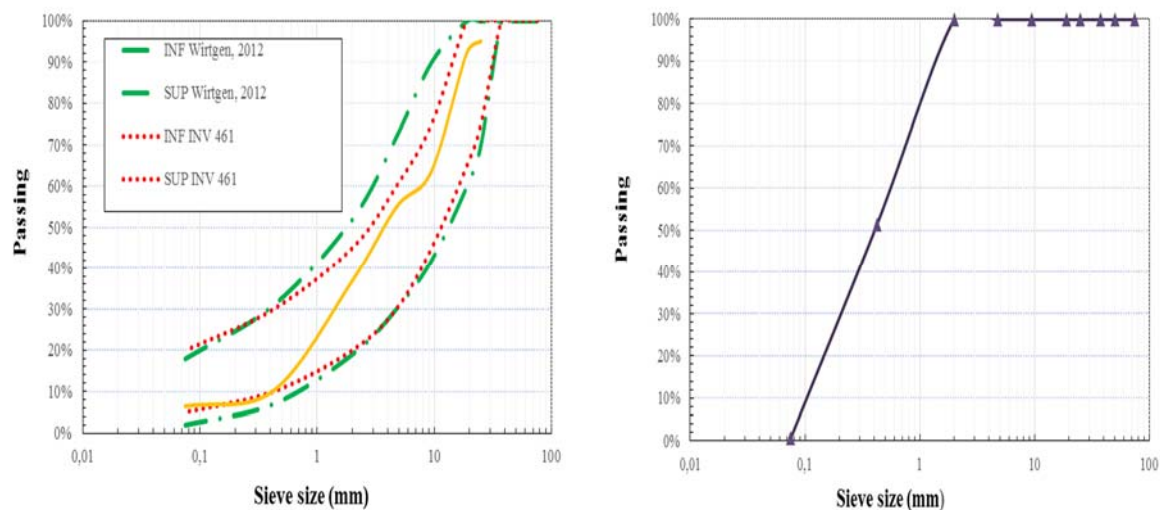


Figure 2. Particle size distribution of: (a) gradation of RAP and INVIAS and Wirtgen specifications limits (b) gradation of crumb rubber

3.1.3. Bitumen Emulsion. The binder used in this study was a slow setting cationic bitumen emulsion with a bitumen content equal to 62.1%. The main characteristics of the emulsion are listed in Table 1.

Table 1. Properties of bitumen emulsion.

Characteristic	Unit	Standard	Value
<i>Characteristic of emulsion</i>			
Sieve test	%	INV E 765-13*	0,10
Residue content by evaporation	%	INV E 771-13	62,1
pH	-	INV E 768-13	2,65
Settlement @ 5 days	%		0,50
<i>Characteristic of recovered binder</i>			
Penetration	dmm	INV E 706-13	60
Softening Point	°C	INV E 712-13	51,60

*INV E: (INVIAS).

3.2. Experimental Program

In order to analyse the influence of crumb rubber in the CREM, four mixes with different dosage of crumb rubber were prepared using the well-known “dry-process”, in which granulated or crumb rubber

is used as a portion of the fine aggregates. In order to obtain a higher mechanical performance, Portland cement with a dosage of 1% by dry weight of aggregates was added as active filler to all the mixes following the standard practices [10]–[13].

3.2.1. Optimum water and emulsion content. The first step in the methodology consisted of determining the optimum water content (OWC) by conducting the modified proctor test following the standard EN 13286-2. The OWC was found to be 6.9%, obtaining a maximum density of 1954.9 kg/m³. Next, the optimum emulsion content (OEC) was determined. Notwithstanding the existence of several empirical equations to determine the theoretical optimal bitumen content (OBC) that covers the surface of the aggregates in HMA, there is no general agreement in the technical literature on the determination of the theoretical emulsion content for cold-bituminous mixtures [13-16]. Thus, the mixes were prepared by keeping the OWC constant, while changing the emulsion content in an interval of 0.8% to get four emulsion contents that were as tested: 2.4, 3.2, 4.0 and 4.8%. Based on the state of the practice [12], [14], the ITS was selected as a response parameter to identify the OEC. The OEC was chosen as the content that exhibited the highest ITS (European Standard EN 12697-23) and TSR values, and also the best volumetric properties such as air voids and bulk density. The OEC that meet those requirements was found to be 3.2%. Furthermore, the Indirect Tensile Stiffness Modulus (ITSM) test was also conducted in accordance with EN 12697-26 (2004).

3.2.2. Mixes Preparation, Compaction and Curing. Mixes were prepared according to the calculated OEC and OWC values, and with four different dosages of crumb rubber: 0.0, 0.25, 0.5 and 0.75% (by weight of dry aggregates). Before mixing procedures, the RAP aggregates were oven-dried at 40 °C until they achieved constant weight in order to control their water content. Next, they were uniformly mixed in a mechanical mixer at room temperature (23°C) during 5 minutes and the other materials were added: 1% of Portland cement (by weight of dry aggregates), crumb rubber, water and asphalt emulsion. The specimens were posteriorly compacted by applying 75 Marshall Hammer blows per side. Each specimen has a diameter of 4" (10.16 cm) and a thickness equal to 2.5" (6.35 cm). They were extruded from moulds after spending 24 hours at room temperature and cured in an oven at 40 °C for 72 hours.

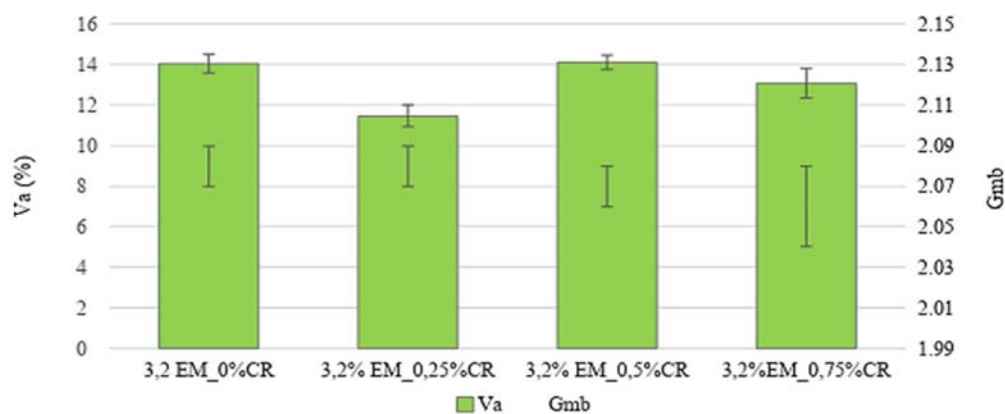


Figure 3. Volumetric properties: void content and dimensional bulk specific gravity (Gmb)

4. Test procedures and results

4.1. Volumetric properties

The Bulk specific gravity (Gmb) for all specimens were determined to characterize weight-volume relationships. Figure 3 shows the volumetric properties of the manufactured CREM. From this figure, a slight reduction in the Bulk specific gravity value can be observed as rubber content increases. The addition of rubber to CREM represents the inclusion of a material with higher volume with respect to

the fine granular fraction, while its density is markedly lower. Regarding the voids content, very high values were obtained compared to those of conventional HMA. In fact, high air void content has been recognized as a particular characteristic of cold mixes [10], [17].

4.2. Indirect Tensile Strength

The ITS test was carried out according to the European Standard EN 12697-23 and has been recognized as a straightforward test to ascertain the moisture susceptibility, which is applied on conditioned samples (soaked samples during 24h at 25°C) and compared with unconditioned or control samples. In this way, the Tensile Strength Ratio (TSR) can be obtained as an index for moisture susceptibility. A minimum tensile strength ratio of 70% is often used as a standard [13], [14].

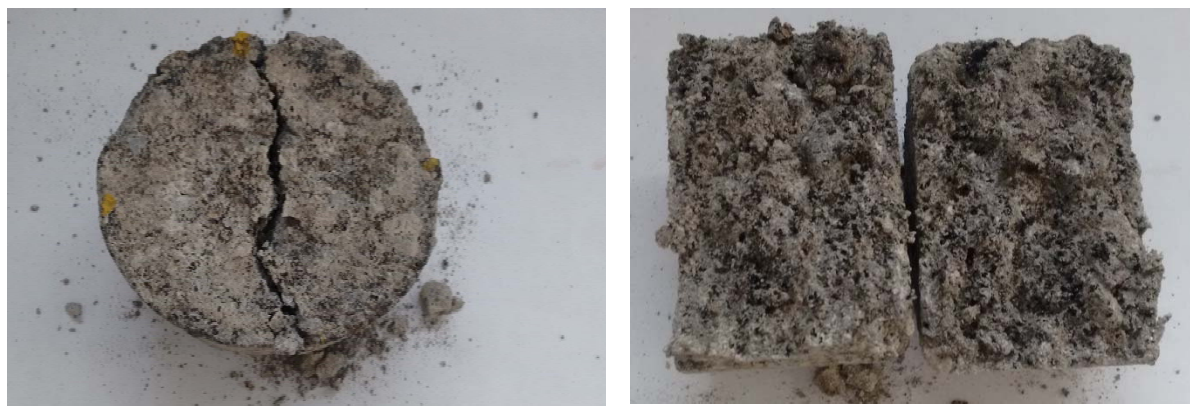


Figure 4. Broken specimen with indirect tensile strength test

Figure 5 shows the result of 3 replications of the ITS test for both dry and wet samples, as well as the respective TSR. The error bars display the standard deviation (SD). It should be noted that all mixes were manufactured with the same emulsion and cement content (3.2% and 1%, respectively).

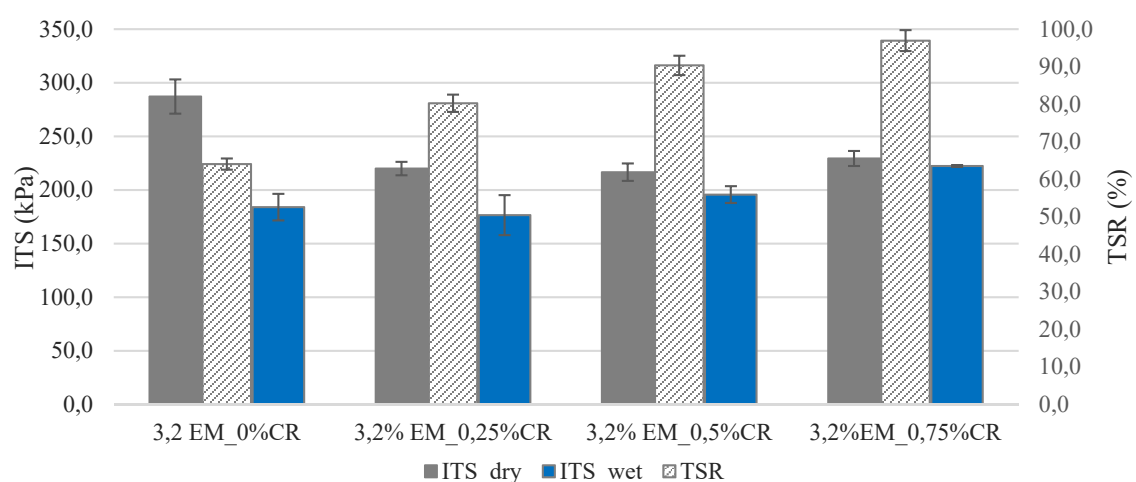


Figure 5. Indirect tensile strength and tensile strength ratio

The control mix, identified as “3.2 EM_0%CR”, depicted the higher ITS dry resistance (ITS_dry), while the values of this property for samples with CR were found to be roughly the same. Similarly, to what has been found for dry conditions, under soaked conditions, the addition of CR seems to reduce the

tensile strength relatively to the control mix. However, as CR increases the ITS_{wet} rises from 176 kPa to 222kPa. The mix with 0.25% CR presented a high variability in the wet ITS value. This result on the SD may be explained by the eventual occurrence of CR segregation during the samples preparation. Regarding the TSR ratio values, all mixes were found to exceed the conventional values of 70% [13], [14]. The addition of rubber seems to positively influence the ITS conserved resistance, in the sense that samples with the higher CR content denoted an improved TSR. However, it should be mentioned, that CR content considered in this study can be considered as low comparatively to other research studies that have considered a CR content as high as 3% [18]. Finally, the rubber addition induced a ITS_{dry} reduction ranging from 20 to 26%.

4.3. Indirect Tensile Stiffness Modulus (ITSM)

The Indirect Tensile Stiffness Modulus (ITSM) test was also conducted in accordance with EN 12697-26 (2004). This test has the capacity of measuring the viscoelastic response of a paving material. The specimens were placed in a controlled temperature chamber assuring that they reached the desired temperature (at least two hours before testing). The target diametral deformation of $5 \pm 2 \mu\text{m}$ was imposed at each peak load for 100 mm nominal diameter specimens. The conditions of the test are reported as follows:

- Temperature: 5, 25 and 40°C
- Load frequency: 0.5, 1, 2, 4, Hz.

At least three specimens were tested for each level in ITSM mode.

Master curves of ITSM were fitted through the sigmoidal model [19]. The method consists of fitting a sigmoidal curve to the measured dynamic modulus test data using nonlinear least square regression techniques. The shift factors at each temperature are determined simultaneously with the other coefficients of the sigmoidal function. The function is given by the following equation:

$$\log|E^*| = \delta + \frac{\alpha}{1 + e^{\beta - \gamma \log fr}} \quad (1)$$

Where δ , α , β and γ are the sigmoidal function coefficients (fit parameters), and fr the reduced frequency, which is given by the following equation:

$$\log fr = \log f + \log a_T \quad (2)$$

Where a_T is the shift factor at temperature T.

Using the dynamic modulus test results measured at three different temperatures and four different loading frequencies, a master curve was constructed for a reference temperature of 25°C for all mixes studied with different CR content. Figure 6 displays the results of the dynamic response of the CREM for a CR content of 0.25, 0.5, and 0.75%, respectively. Overall, the master curves for all mixes perform very flat with respect to the very known shape of HMA master curve. In particular, the control mix (3.2%EM_0%CR) showed a well extended shape which can be interpreted as CREM are not as viscoelastic as HMA. Conversely, mixes with CR exhibited a more pronounce S shape, inducing to a more viscoelastic behaviour. CR mixes showed lower stiffness to low temperature than that of the control mix, this behaviour was conserved at high temperature and high frequencies with exception of the mix containing 0.5%CR. In general, some reduction was observed as main effect of the rubber addition.

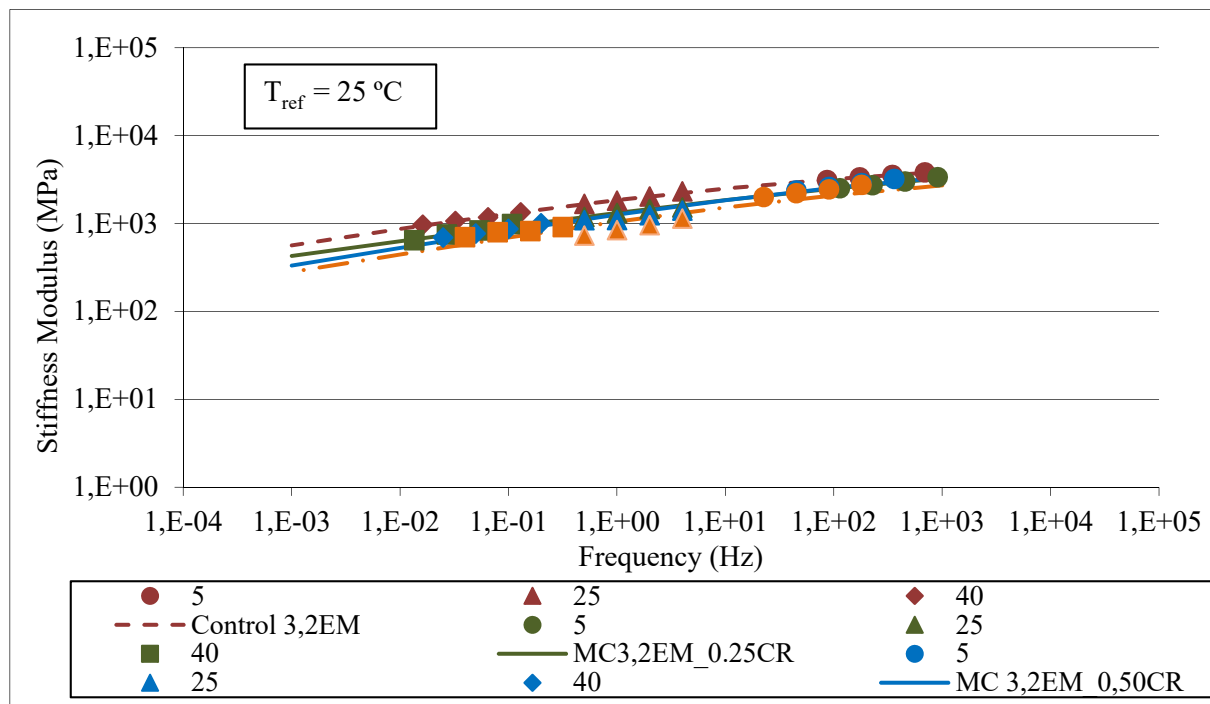


Figure 6. ITSM master curve at 25°C

5. Conclusions

A laboratory investigation was undertaken in order to evaluate the influence and possible benefits of producing cold recycled emulsion mixes with crumb rubber as substitute of fine aggregates. In particular, the response on the mechanical properties was studied by means of the indirect tensile strength test and dynamic modulus. The main conclusions are summarized as follows:

- The addition of CR on cold recycled emulsion mixes increased the air void content in the mix with respect to control mix. In addition, because of the reduced density of the CR, the estimated Gmb was also reduced. Careful analysis should be given to void determination because of the high porosity of cold mixes.
- The indirect tensile strength was reduced with the addition of CR, future efforts should consider alternative ways to improve adherence between CR and emulsion mix. TSR for mixes with CR exceeded the traditional threshold of 0.70 after soaked conditions independently of the CR content.
- Indirect Tensile Stiffness Modulus varied depending on the CR percent, frequency and the temperature. Master curve performed relatively flat with respect of a master curve for a conventional hot mix asphalt.
- Further research should consider different CR contents and emulsion contents. Additional tests evaluating fundamental parameters such as fatigue and creep compliance should be undertaken in order to have a complete window associated with the performance of this potential eco-friendly material.

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