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Mechanical behavior of asphalt mixtures with different aggregate type

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HIGHLIGHTS

- It was identified the influence of aggregate type on the mechanical properties of asphalt mixtures.
- Coarse aggregates have more influence on the stiffness of the asphalt mixture.
- Fine aggregates have more influence on cracking resistance properties.
- The influence of an aggregate depends on the shredding process and the origin.

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ABSTRACT

Measurement of the effect of aggregate type on mechanical properties of asphalt mixtures is a complex and understudied variable. This paper presents main results of an experimental study about the influence of physical properties of different aggregate type on mechanical behavior of asphalt mixtures. With this purpose, twelve different asphalt mixtures have been manufactured, with the same aggregates distribution, but using three different types of aggregates, obtained by two different shredding processes, and four different types of asphalt bitumen (two with different penetration values, one polymer modified bitumen and one with high modulus). Morphological characterization and surface texture measurement have been carried out according to methodologies proposed by Zingg method and ASTM-D3398 Standard. Additionally, stiffness and cracking resistance of asphalt mixtures have been evaluated at four different temperatures by using stiffness modulus test and Fenix Test, respectively. Main results of this study demonstrate that morphology and surface texture of aggregates, both coarse and fine size, influence on stiffness and cracking resistance of evaluated asphalt mixtures, and that this influence depends on the shredding process and the origin of aggregates.

1. Introduction

Asphalt mixture is the most widely used material in roads and highways construction. It is composed of mineral aggregates, asphalt binder and filler. Properties of these materials and their interactions determine the mechanical behavior of asphalt mixtures, and consequently the durability of resultant asphalt pavements over time. Thus, adequate selection of materials is required to obtain correct asphalt pavement performance [1]. In the context of road engineering, aggregates are considered individually as particles or elements that work together forming mineral structure of a pavement [2]. Current studies about morphology of aggregates focus on size, surface texture, angularity and morphology of the particles. In fact, these individual properties also define the mechanical behavior and stability of the mineral structure of asphalt mixtures [3,4]. To determine the general influence that aggregates have on asphalt mixtures is a complex process, due to their chemical characteristics are different depending on their origin and type of rock, while physical properties depend both on the mineralogy and the shredding process [2,5,6]. Morphology and coarse aggregate gradation provides internal friction and the ability of asphalt mixtures to resist traffic loads [7]. Based on revised literature, morphological characteristics have influence on the rutting susceptibility of asphalt pavements, fatigue cracking resistance, stability and other properties of asphalt mixtures [2,7–9]. Moreover, angularity of fine aggregates also has influence on the susceptibility of asphalt mixtures to rutting [10]. Related to the morphology of aggregates, a key factor is the type of Stone crusher

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used to obtain them. Some research studies have demonstrated that an impact crusher with vertical axis produces cubic particles of all sizes, while a cone crusher produces different morphologies depending on the size range [9,11]. Flat and elongated aggregates present high susceptibility to break under traffic loads, modifying aggregates distribution and initial properties of asphalt mixtures [2,8,10]. There is a perception that cubic crushed aggregates, that is, when their diameters ratio is near to 1, produce better behavior of asphalt mixtures. It is considered that ideal morphology of aggregates is cubic shape due to that they present better resistance to rutting [8] and they also provide a better bond of the structure that implies less rotation and movements of the aggregates [12]. Nowadays, there exist different methodologies and parameters to morphologically characterize aggregates such as Zingg method, particle index defined by ASTM-D3398 Standard [13], shape coefficient defined by UNE EN 933-4:2008 Standard [14], and the use of specific image analysis software, among others. Even in some studies there is only considered the crush process type to define aggregate morphology. The variety of methodologies causes that the cubic aggregate concept could be generalized to a greater range of morphologies. According to the above mentioned, some standards in which there is the Chilean Standard, consider the effect of aggregate morphology on asphalt mixtures taking into account that only 15% of aggregates can be of flat type and that it is necessary a minimum value of 90% of crushed aggregates [15]. This causes that different morphologies of aggregates could be considered as similar even when they have different influences in the mechanical behavior of asphalt mixtures. For all these reasons, the aim of this study is to evaluate the effect of morphology and surface texture of aggregates on the stiffness and cracking properties of asphalt mixtures, in a range of working temperatures between −10 and 20 °C, and considering the crushed process type, the origin of aggregates and their properties both in coarse and fine size. The purpose is to identify the morphology and surface texture that provide the best correlation with the mechanical behavior of asphalt mixtures considering stiffness and cracking resistance properties.

2. Materials and methods

2.1. Materials

Different aggregates and bitumen type have been used in this study to manufacture the asphalt mixtures. Used aggregates were: two of fluvial type (AF1 and AF2) and one from quarry (AC), see Fig. 1. Fluvial type aggregates were obtained from the same location and they were mainly composed by dolomite, basalt, dacite, andesite, rhyolite, sandstone, quartz and quartzite. The main difference between the two fluvial type aggregates was their final crushing process. Fluvial type aggregate with more irregular morphology (AF1 in Fig. 1) was obtained by using a cone crusher, while the other fluvial type aggregate (AF2 in Fig. 1) was obtained by using an impact crusher. Aggregate from quarry (AC in Fig. 1) was mainly composed by quartz, biotite and iron oxide. As with aggregate AF1, AC aggregate was obtained by crushing process using a cone crusher. In addition, four types of bitumen were used: two conventional type bitumens according to Chilean specifications (CA-24 and CA-14), and two polymer-modified bitumens, one using SBS polymers and one with high modulus (CA-MP and CA-AM). Characteristics of conventional and unconventional bitumens used in the study are shown in Tables 1 and 2. Finally, a semi-dense asphalt mixture type IV-A-12 according to Chilean specifications was used in the study. Aggregate distribution can be observed in Fig. 2. Asphalt mixture design was carried out by using Marshall Method, obtaining an optimum bitumen content of 5.2% on aggregates weight, for the three types of aggregates used.

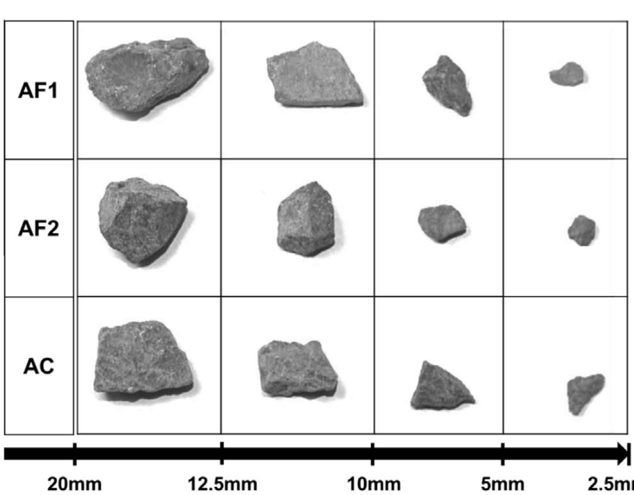

Fig. 1. Morphology of aggregates used in the study.

2.2. Physical and chemical properties of the aggregates

Table 3 shows physical properties and the differences between the aggregates used in the study according to Chilean Standards together with their specifications to be used in asphalt mixtures. Additionally, chemical analysis of aggregates was carried out by using Scanning Electron Microscopy (SEM), see Table 4. Average results obtained showed that the three types of aggregate are quartz type, having a silica (Si) content of 59.9% in the case of AF1, 59.1% in the case of AF2 and 63.3% in the case of AC.

2.3. Morphology of aggregates according to Zingg method

Zingg method is a procedure to classify different coarse aggregate particles according to their morphology [8]. This method requires the length, width and thickness of aggregates with size over 5 mm, to later calculate four parameters: shape factor, sphericity, elongation ratio and flatness ratio. Knowing length and flatness ratio, four different shapes of aggregate can be defined: disc, blade, cubic and rod shape. In order to determine each shape parameter for the studied aggregates, Eqs. (1)–(4) were used, and their results are shown in Table 5.

$$\text{Shape factor} = e/\sqrt{a \cdot L} \tag{1}$$

$$\text{Sphericity} = \sqrt[3]{e * a/L^2} \tag{2}$$

$$\text{Elongation ratio} = a/L \tag{3}$$

$$\text{Flatness ratio} = e/a \tag{4}$$

where L is length in (mm), a is the width in (mm), and e is the thickness in (mm). In addition, Zingg diagram can be built on the elongation ratio and flatness ratio. Depending on the average location of the particles in the quadrant, general morphology of aggregates can be determined. Fig. 3 shows the classification of the aggregates used in the study AC, AF1 and AF2, where it can be observed that the three evaluated aggregates present different morphologies, although all of them are near to the intersection zone of the lines that define the morphology type. According to this classification, AC is a blade type aggregate, AF1 is a disc type aggregate and AF2 is a cubic type aggregate.

2.4. Characterization of the morphology and surface texture according to particle index (PI)

Particle index (PI) represents a general measurement of morphology and surface texture of aggregates and it can be determined according to ASTM-D3398 Standard. This parameter has been determined in the study considering all aggregate sizes in evaluated asphalt mixture except filler, according to Eqs. (5)–(7). Then, PI was evaluated considering different criteria with the aim of determining the most representative criterion of mechanical properties of the asphalt mixture obtained from the experimental phase. Table 6 shows PI values of the three types of aggregates according to the three criteria described below:

- *Criterion I:* All sizes are considered, according to their amount in the designed asphalt mixture.
- *Criterion II:* Only coarse aggregate is considered, according to its amount in the designed asphalt mixture.
- *Criterion III:* Only fine aggregate is considered, according to its amount in the designed asphalt mixture.

$$\text{PI} = (1.25 \cdot V_{10}) - (0.25 \cdot V_{50}) - 32 \tag{5}$$

$$V_{10} = \left[1 - \left(\frac{M_{10}}{s \cdot V}\right)\right] * 100 \tag{6}$$