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Use of angle of repose of aggregates as an indicator of asphalt concrete properties

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HIGHLIGHTS

- Aggregate texture play important role in mechanical response of asphalt concrete.
- Angle of repose can be used to capture changes in aggregate morphology.
- Strong +ve correlation was found between angle of repose and Marshall parameters.
- Weak –ve correlation was found between angle of repose and Marshall flow values.

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ABSTRACT

Morphological characteristics of aggregates play a significant role in overall response of asphalt concrete under mechanical loading. Due to its simplicity, minimal resources, and less testing time, Angle of Repose (AoR) has been used by various researchers to characterize morphological characteristics of aggregate. This work presents the results of an experimental study to develop interrelationship between AoR and macroscopic response of Asphalt Concrete (AC). For this purpose, (i) aggregates were artificially smoothened through abrasion to different levels of texture/smoothness, and (ii) AoR was measured. Three AC mixtures were prepared using these processed aggregates and were tested for volumetric, strength and flow properties. A strong positive correlation was found between AoR and Marshall parameters (stability, Marshall quotient, retained stability, retained Marshall quotient). A weak negative correlation was found between AoR and Marshall flow. This can be attributed to interparticle resistance developed during compaction and mechanical loading. Thus, it can be concluded that AoR can be effectively used to capture changes in aggregate morphology and AC response.

1. Introduction

In a flexible pavement, stress induced by vehicles is transferred to underlying layers. As topmost layer in direct contact with vehicle tires, Asphalt Concrete (AC) experiences highest stress. The strength of this AC layer is derived from its constituents like aggregate and asphalt binder. Since aggregates encompass significant proportion of AC, applied stress is primarily resisted by aggregate matrix. Sliding of aggregate over each other can lead to excessive deformation under wheel path. This necessitates the usage of aggregate that offers higher friction so that individual aggregate particles are less likely to slide over each other. On the other hand, propagation of cracks (developed under tensile stress) is primarily resisted by aggregate packing. A well-packed aggregate matrix increases the crack propagation length before complete failure. Thus, factors like aggregate packing, and interparticle friction influences the mechanical response of compacted AC mixture. A well-designed mixture can offer more resistance to distress mechanisms like rutting, and fatigue. Consequently the service life of pavement is enhanced.

It is well-accepted fact that morphological characteristics of aggregate influence packing characteristics and interparticle properties of aggregate significantly. Shape, angularity, and surface texture are some examples for these morphological characteristics. During compaction process, flat and elongated aggregates have a tendency to align themselves with horizontal. Further, flat and elongated aggregates tend to break along their axes compared with cubical aggregates. On the other hand, spherical aggregates exhibit higher tendency to roll under applied stress when compared to cubical aggregates. Similarly, rough textured aggregate offers more resistance to flow when compared to smooth textured aggregate.

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Thus, it can be concluded that angularity and surface texture affect mutual interactions between aggregates and consequent packing characteristics.

A variety of techniques have been developed by researchers to evaluate aggregate characteristics. These techniques range from traditional to advanced computer based techniques [2]. Variants of flakiness and elongation test are examples for traditional techniques (BS 812-105.2:1990; IS 2386 Part 1; ASTM D 4791). All these variants essentially measure aspect ratio of aggregates. These traditional techniques are primarily labor-intensive, subjective, and time-consuming testing practices. Thus, these traditional techniques have been used reluctantly on routine basis. Laser scanning systems [20], Image processing algorithms [29,26], and Fourier transform interferometry system [25] are some examples for advanced computer based techniques. Most of these advanced techniques have capability to measure volume, roundness, texture, and aspect ratio of aggregates accurately. However, initial cost of these equipment and sophistication of test procedure has limited its utilization for routine testing.

Various studies have been conducted to relate morphological characteristics of aggregate with macroscopic properties of mixtures (under bound and unbound condition) [5,15,18,19,16,26]. Ahlrich [1] attempted to quantify aggregate shape and texture (through aggregate shape tests) and relate it to permanent deformation characteristics of AC. Ahlrich [1] found that angular particles and rough texture increased the stability of AC while reducing rutting suceptibility. Krutz and Sebaaly [24] found a strong correlation between the rutting potential of HMA mixtures and morphological characteristics (specifically shape and texture) of coarse aggregate particles. Masad et al. [26] reported a similar strong correlation between rut resistance of AC mixtures and fine aggregate angularity. Petersen et al. [28] reported that surface texture and shape of aggregate influences the AC mixture properties to a larger extent. Chen et al. [8] found that use of cubical aggregate increased rut resistance, indirect tensile strength, and resilient modulus of AC. Tutumluer and Pan [32] proposed angularity index and surface texture index parameters to quantify aggregate morphology and found a strong correlation with permanent deformation characteristics of unbound materials. Shu et al. [31] reported that aggregate angularity increases interlocking between coarse aggregate particles. Recently, Kumar et al. [23] proposed second order relationship between indirect tensile strength of AC and Angle of Repose (AoR) of aggregates.

Due to its simplicity, repeatability, and less time for testing, AoR has attracted attention of several researchers [34,11,23]. Most of the researchers have reported that numerical values of AoR indicate aggregate angularity indirectly. Various researchers have reported that AoR is significantly affected by particle shape and interparticle friction [6,10,7,35,9,22]. Miura et al. [27] reported that angle of repose increases with roughness of boundary condition. Burkalow [6] reported a strong positive correlation between density of mixture and AoR. Fowler and Chodziesner [10] found that AoR of sand was significantly affected by average diameter of sand particle. Riley and Mann [30] reported that proportaion of cubical particles increases the number of contact points within aggregate matrix. This increase in number of contact points increases the AoR of mixture. Wouters and Geldart [34] reported that AoR decreased with increasing surface area of the particles. Chen et al. [8] found that particle index is robust enough to capture elongation ratio, flatness ratio, shape factor, and sphericity of aggregate. Ghazavi et al. [12] proposed a linear relationship between AoR and internal angle of friction.

In general, the behavior of aggregate particles (both in bound and unbound form) is quite complex and specific to aggregate source and type. These issues further complicate the mechanical response of AC. Simultaneously, practicing engineers are looking for test practices that require inexpensive equipment and can be implemented field conditions on routine basis. Most of the literature used aggregates from different sources to capture effect of aggregate morphology. However, factors like geological origin, source of aggregate, and processing methodology affect any such morphology quantification significantly. The objectives of present work are to relate (i) aggregate morphology with AoR, and (ii) aggregate morphology with strength, volumetric and flow properties of compacted AC.

2. Materials, characterization, and mixture design

Materials used in this study were tested/processed at three levels i.e. (i) in as-procured condition (binder and aggregate), (ii) processed aggregate (through artificial texturing/smoothening), and (iii) compacted AC mixture. Initially, asphalt binder and aggregate obtained (in raw form) were tested for their conformity to relevant specifications. In the second stage, morphology of aggregates was artificially changed through abrasion using Los Angles abrasion testing machine. These processed aggregates were tested for AoR to capture aggregate characteristics. In the third stage, AC mixtures were prepared using asphalt binder and processed aggregates. The compacted AC mixtures were tested for volumetric, strength and flow properties. Finally, properties of constituent materials and compacted mixtures were compared. A flowchart of activities carried out is presented in Fig. 1.

2.1. Raw materials

Aggregates from a local quarry near New Delhi, India were used in this research. The aggregates were tested for its physical properties as per relevant Indian standards for shape (IS: 2386 [Part-I]-1963), water absorption (IS 2386 [Part-III]-1963), specific gravity (IS 2386 [Part-III]-1963), impact value (IS: 2386 [Part-IV]-1963), crushing strength (IS: 2386 [Part-IV]-1963) and abrasion resistance (IS 2386 [Part-IV]-1963). The impact value, flakiness index, elongation index, Los Angeles abrasion value, specific gravity, and absorption value of aggregate source was found to be 18.69%, 5.88%, 20.3%, 19.75%, 2.65 and 1%, respectively.

To check the effect of binder grade on mechanical response of compacted AC mixtures, asphalt binders of two different grades i.e. VG 30 and PMB 40 were used in this research. These binders were sourced from a reputed refinery located in northern part of India. Both asphalt binders were checked for conformity with relevant Indian standards (IS-73 2012) and it was found that it satisfied the requirements. Some of the important properties specified in IS 73 [14] and the test results are presented in Table 1. The specifications limits are indicated in parenthesis within each cell. More details regarding materials uses can be found elsewhere [33].

2.2. Aggregate processing

As mentioned previously, one of the goals of current work was to evaluate the effect of aggregate morphology on AoR and macroscopic properties of AC mixture. To obtain aggregates with different roughness/surface texture, aggregate from single source were synthetically smoothened (textured) in laboratory. Such an approach eliminated the effects of other variables like geological origin, mineralogical composition, quarrying process, crushing procedure, etc. In this work, aggregates were abraded to 4 levels of texture (i.e. roughness level) apart from raw aggregate. For this purpose, 8 kg of aggregates of particular size were fed into Los Angeles abrasion machine without any steel ball charge. These aggregates were abraded for 1000, 2000, 3000, and 4000 repetitions. These numbers of repetitions were chosen so as to obtain