# Investigation into Flat and Elongated Particles Ratio for Asphalt Mix Design Using a Modern Laser Technique

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## ABSTRACT

Flat and elongated particle ratio is a shape characteristic for coarse aggregates used in pavements. The ASTM D 4791 is the standard test method to determine flat and elongated coarse aggregate particles in asphalt mixes. However, this method is subjective, making it less reliable to accurate measurements. The objective of this study was to investigate three flat and elongated particles ratios (FERs); 2:1, 3:1 and 5:1 using a modern 3-D laser scanning technique and compare results with ASTM D 4791. Based on the ASTM D4791, the Superpave specification allows for a maximum of 10% coarse aggregates to have FER of 5:1 in asphalt mixes. Eight crushed stones used for road construction in South Africa were investigated. The results indicate that three crushed stones would be rejected by the Superpave specification whereas all eight crushed stones could meet the specification based on the results from the 3-D laser scanning method.

## INTRODUCTION

The traditional ASTM D4791 test method used to determine flat and elongated coarse aggregate particles in asphalt mixes is less reliable to accurate measurements as the entire procedure is highly subjective hence liable to human errors. There is a general interest worldwide in employing imaging and automated techniques to characterize the shapes of aggregates used in pavements. The main advantage these techniques is the ability to capture three-dimensional (3-D) information of aggregate shapes, hence allowing for a more accurate and precise measurements.

Aggregate shapes govern the deformation and strength characteristics of asphalt mixes. Modern asphalt mix design methods place emphasize on aggregate shape properties that improve performance of the pavement. For instance, equal-dimensional aggregate particles are generally preferred over flat and elongated aggregates in the asphalt mix. The propensity of flat and elongated particles to lock up or break during compaction may lead into difficulties in achieving air voids requirements in asphalt mixes. Accordingly, various mix design specifications limit the amount of flat and elongated particles in the asphalt mix. .

Several studies have shown that aggregate shape parameters measured using automated and advanced imaging techniques are more accurate when compared with standard methods (Brian et al. 2005, Rao et al. 2001, Anochie-Boateng et al, 2012, Prowell and Weingart, 1999.). Marez and Zhou (1999) underlined advantages of digital image system as reliable, increased testing and quicker process control adjustment to reduce off-specification material and less subjective than manual measurements. Most of these techniques make use of the aggregate particle dimensions (length, width and thickness) as well as area and volume to compute indices describing aggregate shape.

The objective of this study was to investigate three flat and elongated particles ratios; 2:1, 3:1 and 5:1 using a modern 3-D laser scanning technique and compare results with ASTM D 4791. Eight aggregate types used in pavement construction in South Africa including recycled asphalt pavement (RAP) and alluvial gravel were used for this investigation. Currently, only the ratio of 5:1 is popularly used to determine the maximum allowable flat and elongated coarse aggregate particles in asphalt mixes. The major concern is that almost all coarse aggregate meet the 5:1 criterion but does not usually reflect performance of the mix in the pavement.

## FLAT & ELONGATED PARTICLE RATIO

As mentioned previously, the ASTM standard procedure ASTM D 4791 is the current test method for determining flat and elongated aggregate particles in coarse aggregates. Flat and elongated particle ratio (FER) can be defined as the ratio of the longest dimension (orthogonal) of the aggregate particle to the shortest dimension (orthogonal). Rao et al (2001) used imaging technique to compute FER ratio of an aggregate particle by using equation 1.

$$FER = \frac{d_L}{d_s} \tag{1}$$

where;
$d_L$ = Longest dimension of an aggregate particle, and
$d_s$ = Shortest dimension of an aggregate particle.

In the ASTM D 4791 test method, a proportional caliper device is set at pre-defined ratios of (2:1, 3:1 or 5:1) depending on the applicable specifications, to measure the ratio of longest to the shortest dimensions of an aggregate particle. Although there are some differences in their precise definitions, the long, intermediate, and short dimensions of an aggregate particle are shown in a bounding box in Figure 1. It is possible to measure these dimensions manually using callipers, although this is time consuming and any set of measurements may be subjected to user variation and human errors.

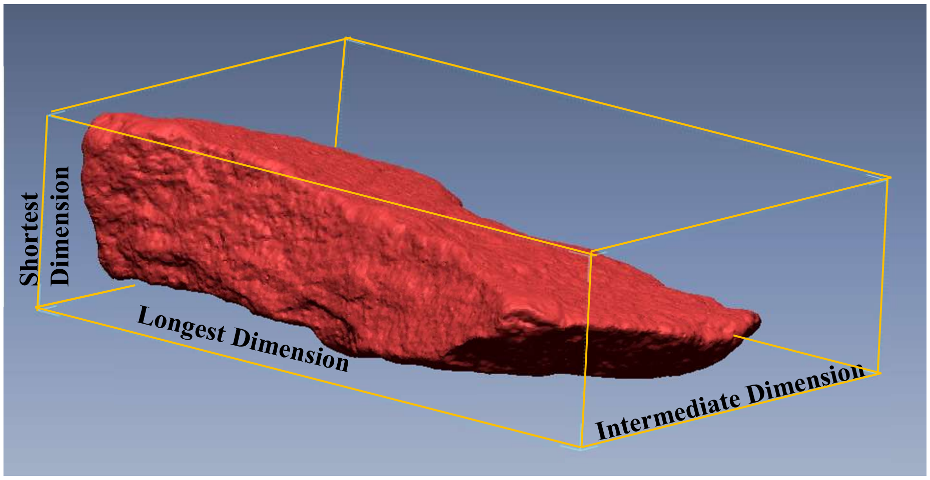

**Figure 1. 3-D laser scanned and modelled aggregate particle in a bounding box.**

The ASTM D 4791 is the recommended method in Superpave mix design for the evaluation of the amount of flat and elongated particles in the mix (Asphalt Institute, 2014). Flat and elongation ratio is calculated by dividing the mass of flat and elongated particles to the total mass of the sample, and expressed as a percentage. The Superpave procedures recommend the ratio of 5:1 (i.e., maximum dimension is five or more times the minimum dimension) to determine the flat and elongated particles in coarse aggregates. A maximum of 10% flat and elongated particles are specified for asphalt mix designs.

The FER (percentage) is calculated by the following equation:

$$F \& E = \left( \frac{M_{FE}}{M_T} \right) \times 100 \qquad (2)$$

where,
$M_{FE}$ = mass of flat and elongated aggregate particles
$M_T$ = the total mass of sample tested

Figure 2 illustrates a typical flat and elongated particle compare with a cubical particle in the matrix of an asphalt mix. If these particles are present in large quantity, then fracturing can effectively change the aggregate grading as larger flat and elongated particles are broken into smaller, more cubic particles. Also, the fracturing of flat and elongated particles within the asphalt create aggregate faces that are uncoated with asphalt binder, which can adversely affect durability of the mix.

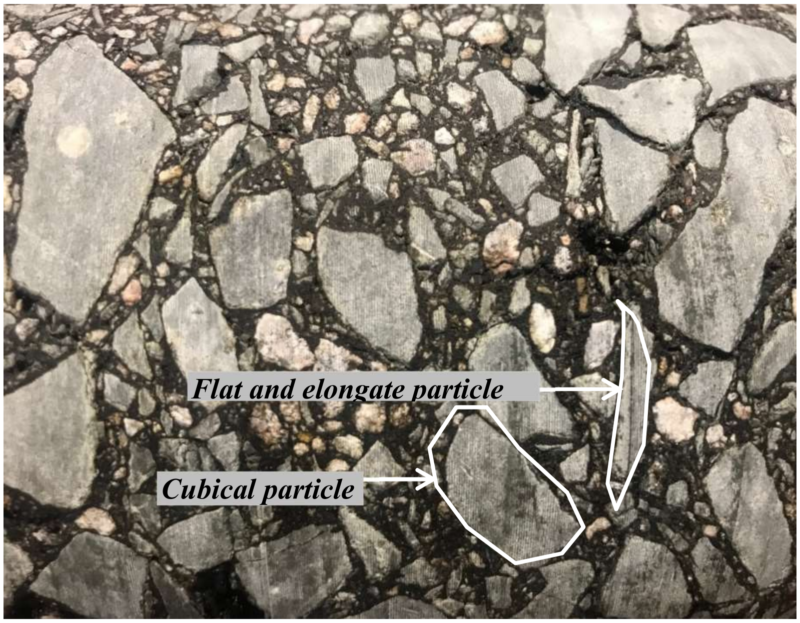

**Figure 2. Illustration of aggregate particle shapes in an asphalt mix.**

## AGGREGATES SAMPLING AND PREPARATION

Eight aggregate types commonly used for road construction in South Africa were investigated in this paper. The aggregates included six crushed stones (i.e. granite, tillite, quartzite, hornfels, andesite and dolerite), alluvial gravel and RAP. The crushed stones were sourced from commercial quarries, whereas the alluvial gravel and RAP were sourced from Molopo River in the North West province and an asphalt plant in the Kwa-Zulu Natal province of South Africa, respectively.

Sampling of aggregates at stockpiles in the quarries was done randomly at different positions as per South African Technical Methods for Highways 5 (TMH 5, 1981). The sample selection ensured that materials with varying shape properties were included in the study. The alluvial gravel with round shaped particles were used as a control sample, whereas the RAP was used as a reference to assess the shape of aggregate particles after being subjected to traffic and compaction. Table 1 show the eight aggregate materials used for in this study.

**Table 1. Aggregate samples.**

| Aggregate type | Rock type | Crushed shape |
|---|---|---|
| **Granite** | Igneous | Fair |
| **Tillite** | Sedimentary | Fair |
| **Quartzite** | Metamorphic | Good |
| **Hornfels** | Metamorphic | Fair |
| **Alluvial gravel** | Sedimentary | N/A |
| **RAP** | N/A | N/A |
| **Andesite** | Igneous | Good |
| **Dolerite** | Igneous | Good |

## LASER-BASED FLAT & ELONGATED RATIO

All eight samples for this study were scanned in a modern laser scanning device available in South Africa to compute for their FER. The capability and accuracy of the laser scanning device to determine the FER was accomplished in previous studies (Anochie-Boateng et al., 2010). Figure 3 shows a typical scanning and modelling of aggregate particle from the laser scanning system.

**Figure 3. Scanning and modeling of aggregate particles in the 3-d laser scanning system.**

Representative samples were obtained from each aggregate type by means of quartering and sieve analyses were performed. Following the sieve analyses, a total of 30 particles were selected from aggregates retained on coarser sieve sizes (i.e. 4.75, 6.7, 9.5, 13.2 and 19.0 mm) for laser scanning. 150 particles of each source or a total of 1200 aggregate particles representing the eight samples were scanned. The particle selection was done such that different aggregate shape properties were represented. For each aggregate type, flat and elongated, angular, round, cubic, rough and smooth aggregate particles were visually identified and randomly selected to constitute the aggregate materials tested.

The steps developed by Anochie-Boateng et al. (2011) to compute the FER from laser scanning system were followed:

1. Obtain the three orthogonal dimensions (length, width, thickness) of individual aggregate particles from a 3-D bounding box generated by the laser scanning software.
2. Determine flat and elongated particles based on the dimensions of the particles in the bounding box, and group them according to the three ratios (2:1; 3:1 and 5:1).
3. Obtain the volume of flat and elongated aggregate particles directly from the laser scanning software.
4. Obtain total volume of all scanned aggregates particles including the non-flat and elongated particles directly from the laser scanning software.
5. Compute FER by dividing the total volume of flat and elongated scanned particles by the total volume of all particles scanned using the proposed equation below.

$$F\ \&\ E_v = \left(\frac{V_f}{V_T}\right)\times 100 \qquad (3)$$

where,

$F\&E_v$ = flat and elongated ratios based on volume
$V_f$ = total volume of flat and elongated aggregates particles scanned
$V_T$ = total volume of the aggregate particles scanned

## DISCUSSION OF RESULTS

Figure 4 compares the FERs obtained from the ASTM D 4791and the 3-D laser-based volume methods. The results are also summarised in Table 2 for all eight materials tested with their values of mean, standard deviation and coefficient of variation of both methods. For each aggregate type, the percentage of flat and elongated (F&E) particles obtained from both methods were plotted against the three FERs; i.e. 2:1; 3:1 and 5:1. The standard method indicates that samples with less F&E particles (gravel, andesite and dolerite) had lower percentages of F&E particles especially at FER of 2:1, whilst the samples with more flat and elongated particles (i.e. granite, tillite, hornfels and quartzite) had high percentages of F&E at all three FERs (2:1; 3:1; and 5:1).

The highest percentage of F&E particles was obtained for the ratio of 2:1. On the other hand, the lowest percentage of flat and elongated particles was obtained based on the ratio of 5:1 (recommended ratio by Superpave). Also, the results show that apart from the alluvial gravel, andesite and dolerite crushed stone (at FER of 2:1), the 3-D laser scanning method (automated) generally provided lower percentage of F&E particles than the standard ASTM D 479 method (manual). The FER of 3:1 provides a more consistent results for all eight aggregate materials based on measurements from the two test methods.

Since coefficient of variation of 3-D laser method is lower that coefficient of variation of the standard ASTM D 4791 method, therefore 3-D laser method is more consistent. The observed variations in the results, however, could be associated with manual process involved when using proportional caliper in the ASTM D 4791. For example, pulling a particle horizontally through the smaller opening of the caliper system without rotating, maintaining contact of the particle with the fixed post at all a time is very subjective and can introduce errors depending on the technician. In comparison, the automated laser-based method would mitigate human errors associated with the standard ASTM D 4791 method. Probably, due to their natural shapes, significant errors could be introduced during the process of testing gravels with the standard method when compared to the other aggregate types.

As mentioned previously, the Superpave specification allows for a maximum of 10% coarse aggregates to have FER of 5:1 in asphalt mixes. Based on this specification, three crushed stones (i.e. granite, hornfels and quartzite, see Table 3) would be rejected whilst all crushed aggregates scanned in the laser method met the specification.

Based on Equation 1, the longest and shortest dimensions of aggregate particles (obtained from the laser) were used to compute the FERs of the samples. The results for all eight materials are summarised in Table 3 in the order of increasing FERs. For equal dimensional aggregate particles such as round aggregates, the flat and elongated ratio approaches a value of 1 (see Equation 1), and as aggregate particles become more flat, the FER increases. As expected, the gravel material is more rounded whilst the results indicate that quartzite is more flat and elongated. The distributions of FERs for the samples based on dimensions are presented in Figure 5. This was done to purposely verify the results obtained for the gravel, dolerite and andesite. It can be seen that the three samples have more rounded particles when compared with granite, tillite, Hornfels and quartzite.

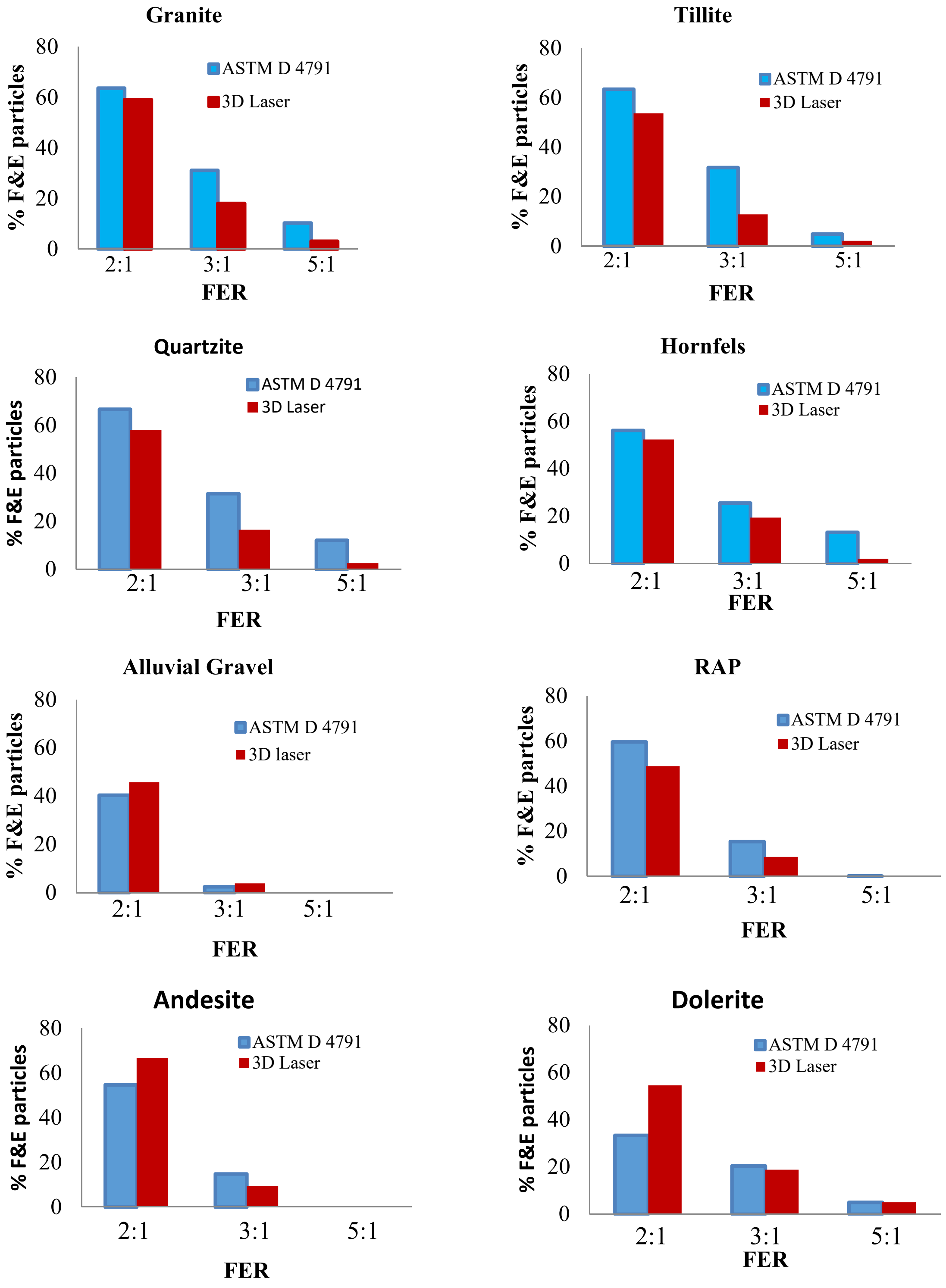

**Figure 4. FER for crushed stones based on ASTM 4791 and 3-D Laser Methods**

**Table 2. Results Comparing ASTM 4791and 3-D Laser Methods**

| Aggregate Type | FER (%) for 2:1 | | FER (%) for 3:1 | | FER (%) for 5:1 | |
|---|---|---|---|---|---|---|
| | ASTM D 4791 Method | 3-D Laser Method | ASTM D 4791 Method | 3-D Laser Method | ASTM D 4791 Method | 3-D Laser Method |
| Granite | 64 | 59 | 31 | 23 | 10 | 3 |
| Tillite | 63 | 54 | 32 | 16 | 5 | 2 |
| Quartzite | 67 | 58 | 32 | 20 | 12 | 3 |
| Hornfels | 56 | 52 | 26 | 24 | 13 | 2 |
| Alluvial Gravel | 40 | 46 | 2 | 5 | 0 | 0 |
| RAP | 60 | 49 | 15 | 11 | 0 | 0 |
| Andesite | 55 | 67 | 15 | 9 | 0 | 0 |
| Dolerite | 33 | 54 | 20 | 19 | 5 | 5 |
| Mean | 54.75 | 54.88 | 21.63 | 15.88 | 5.63 | 1.88 |
| SD | 11.31 | 6.09 | 9.99 | 6.45 | 5.12 | 1.69 |
| CoV | 20.66 | 11.10 | 46.20 | 40.63 | 91.02 | 90.13 |

**Table 3: FER based on Equation 1.**

| **Aggregate type** | **FER** |
|---|---|
| Alluvial gravel | 1.94 |
| Andesite | 2.09 |
| Dolerite | 2.21 |
| RAP | 2.28 |
| Granite | 2.50 |
| Tillite | 2.51 |
| Hornfels | 2.60 |
| Quartzite | 2.63 |

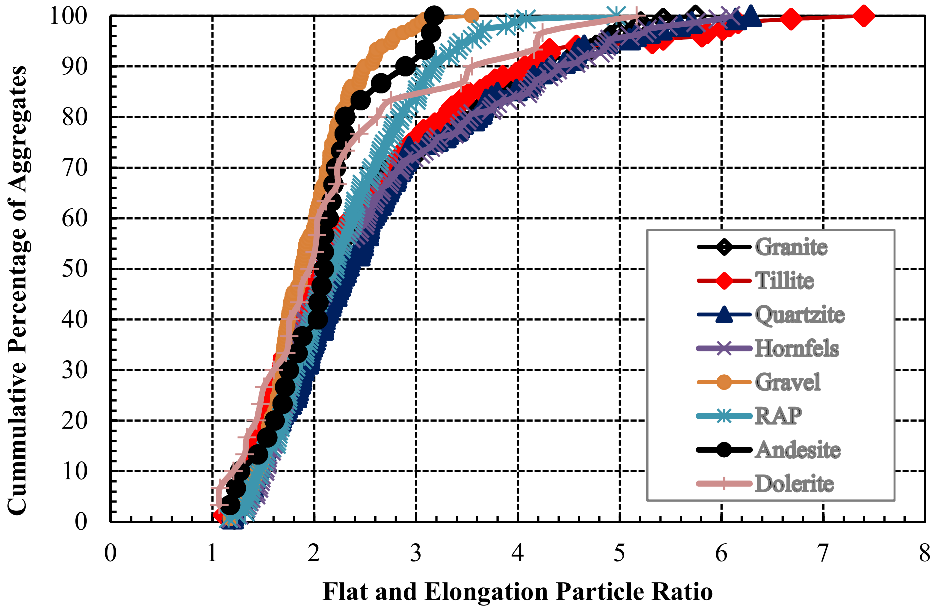

**Figure 5. Distributions of flat and elongation ratio.**

## CONCLUSIONS

From the work presented in this paper, it is evident that the standard ASTM D4791 could over-or under-estimate the percentage of flat and elongated (F&E) aggregate particles in asphalt mixes. The results from the study indicated that granite, hornfels and quartzite materials would be rejected by the ASTM D 4791, whereas the automated 3-D laser method indicated otherwise. The FER of 5:1 for aggregates used for a specification in the Superpave asphalt mix design would therefore, require further investigation using automated techniques that are more accurate than the ASTM D 4791. The long term implications of automation would be higher reliability of results and possible adjustments in current specifications to include marginal aggregates that may lead to cost savings.

Overall, the FER of 3:1 provided a more consistent results for all eight crushed stones investigated using both the traditional and 3-D laser methods. Future assessment is however, required before specifications are set based on this ratio. In addition, it is important to mention that the FER of 5:1 would need reassessment for aggregate samples with more rounded particles as well as non-conventional aggregate materials such as reclaimed asphalt pavement.

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