Application of Advanced Laser Technology to Determine Aggregate Shape Properties

ROAD PAVEMENTS FORUM

TWENTY-EIGHTH MEETING
CSIR International Convention Centre, Pretoria
19 & 20 November 2014

Joseph Anochie-Boateng

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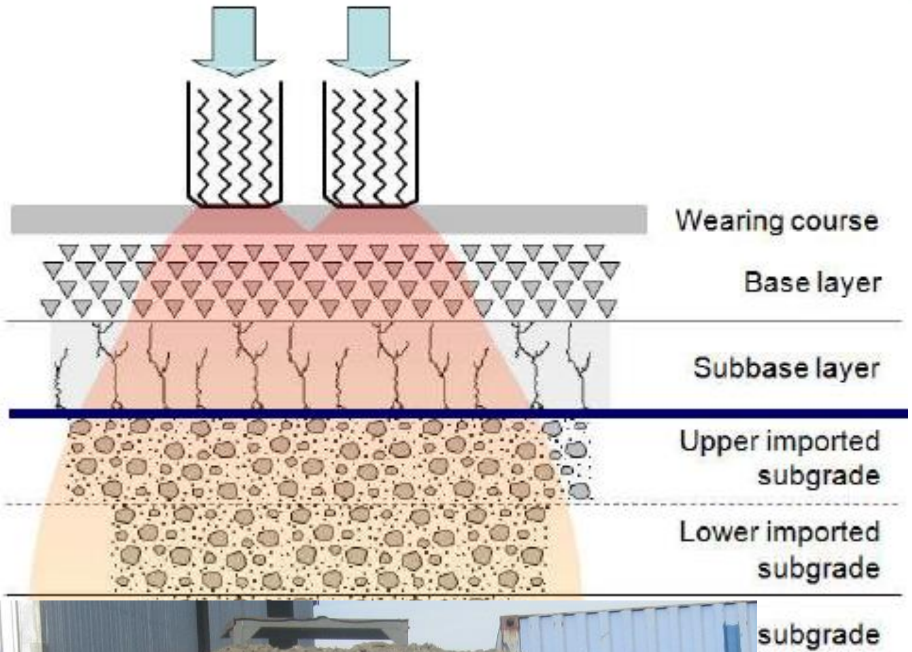
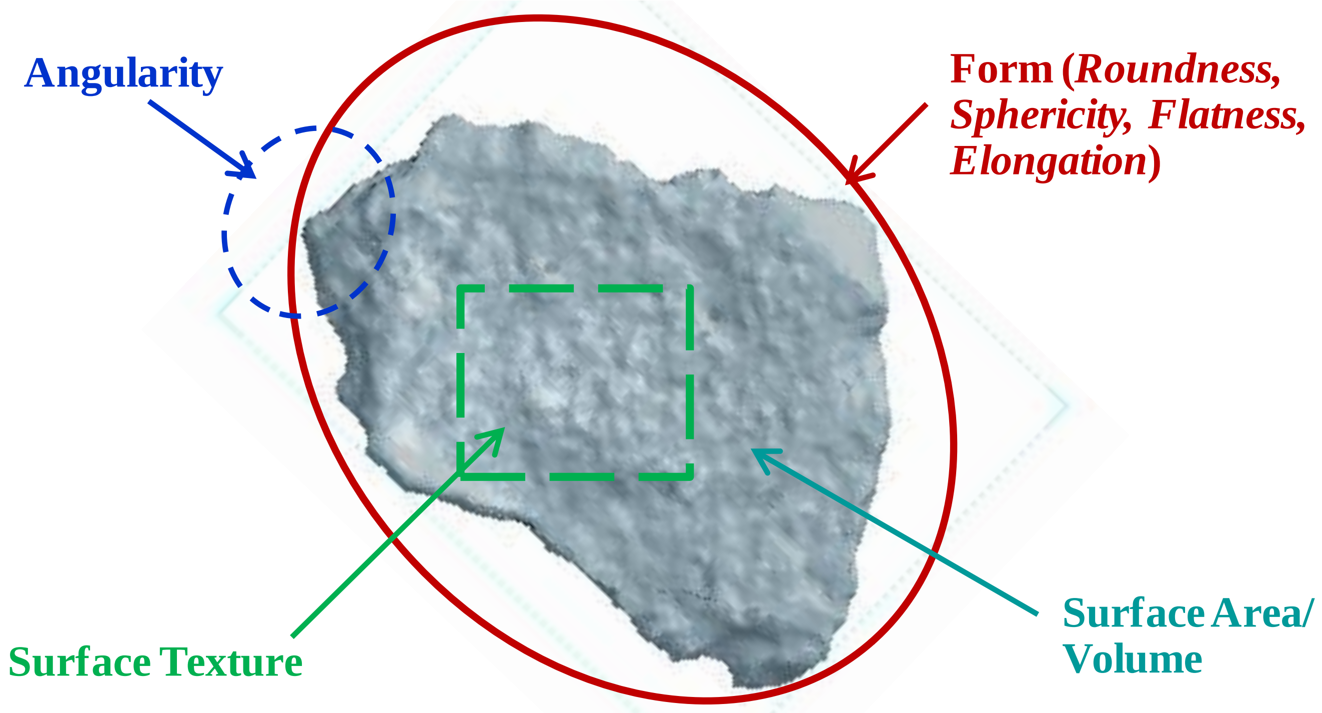
Background



- Rock aggregates make up more than 85% Portland cement concrete and 90% of asphalt pavements surfacing materials
- Coarse aggregates constitute the skeleton and occupy by far the highest mass or volume
- Single & double seal road surfaces, essentially coarse aggregates

Background

- Fundamental **shape** properties of aggregates have not been accurately quantified historically, because of their irregular and non-ideal 3D shapes
- **Insufficient knowledge** regarding aggregate **shape/ surface characteristics** and their influence on the performance of roads



Current Methods

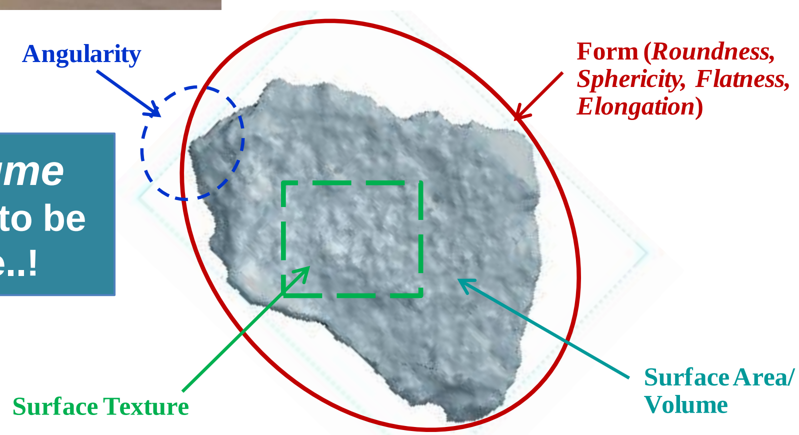
- **Lack of accurate test methods** for modelling the 3D effect of aggregate packing and performance (***Only flakiness test in TMH 1 is the direct method for measuring aggregate shape properties in SA***)
  - ***Overseas not different from SA; Flakiness test used in Europe; Flat & Elongation test used in the USA***

Surface texture: No direct standard method

- **Voids are used to get indication of surface texture (ASTM D 3398)**

Surface area / Volume

- **Particle assumed to be spherical in shape..!**



Angularity – fractured faces, visual..!

Current Methods

- All aggregates presented here are retained on 19 mm sieve by current standard **grading** methods (e.g., TMH1, ASTM, etc.)

Gravel

Crushed stone

Slag

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Current Methods

- Surface area of aggregates for asphalt mix design is obtained from the following formula:

$$SA = \frac{1}{100} \sum PC$$

SA = Surface area of the aggregate (m^2/kg)
P = Percentage by mass passing sieve sizes
C = Surface area factor (m^2/kg)

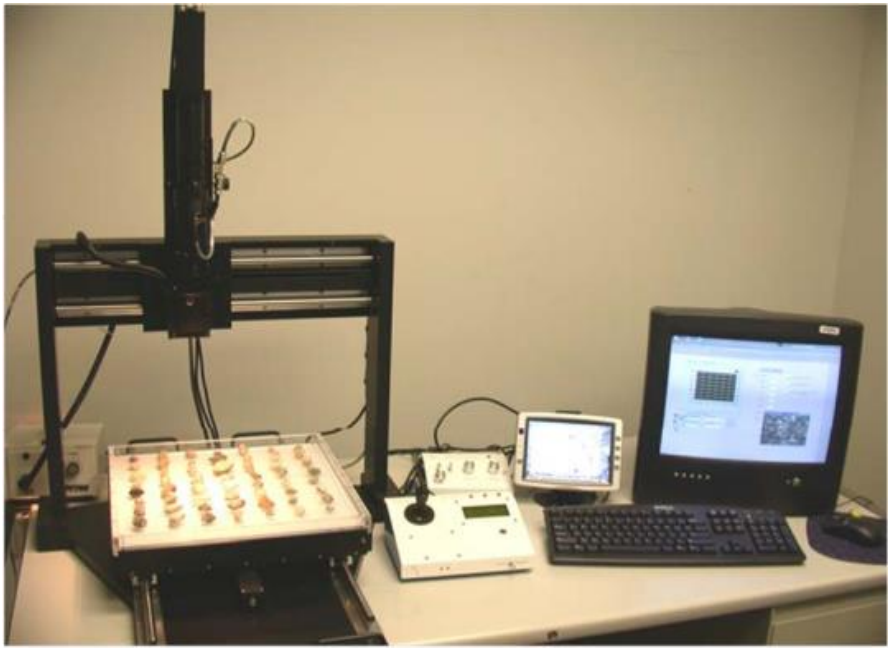
- **Hveem method (1942)** assumes **only one fixed value of *C*** for coarse aggregates
- C factors are based on an assumption that aggregate particles are **spherical** in shape

Sieve Sizes (mm)	Surface Area Factor (m^2/kg)
26.5	0.41
19.0	
13.2	
9.5	
6.7	
4.75	0.41
2.36	0.82
1.18	1.64
0.600	2.87
0.300	6.14
0.150	12.29
0.075	32.77

Advances in Aggregate Shape Characterisation

- Aggregate imaging techniques

Aggregate Image Analyser (2003)



Aggregate Imaging System (2007)

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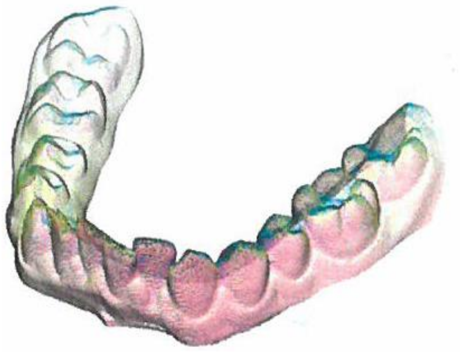
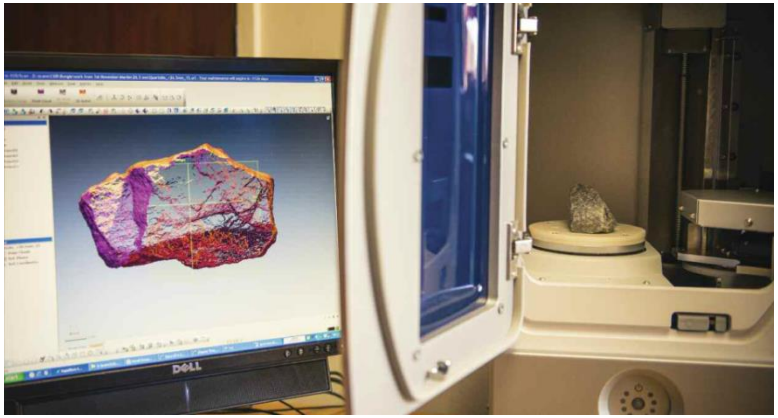
Advances in Aggregate Shape Characterisation

- **2009**: Transport Infrastructure group at CSIR investigated the use of laser scanning to evaluate aggregate shape properties
- It was found that a portable 3D laser device used in the health care field to visualise dental and orthopaedic structures could model the exact shapes of aggregates





***** CSIR sponsored the purchase of the laser equipment and funded the research (R 8 Million in the past 5 years)***

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3D Laser-Based Method

Surface area, Volume

- Direct measurements from the laser

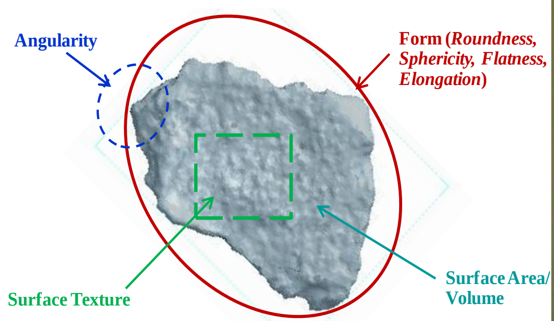
Form (Flatness, Elongation)

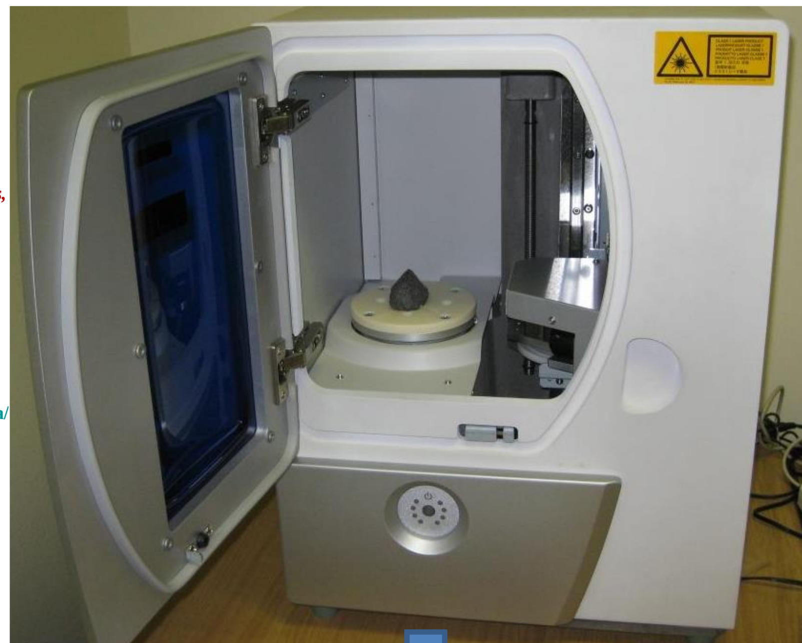
- Direct measurements

Form (Sphericity, Roundness)

$$Sphericity\ (\psi) = \frac{\sqrt[3]{36\pi V^2}}{A}$$

$$Roundness = \frac{V}{A\sqrt[3]{(abc)}}$$





Angularity

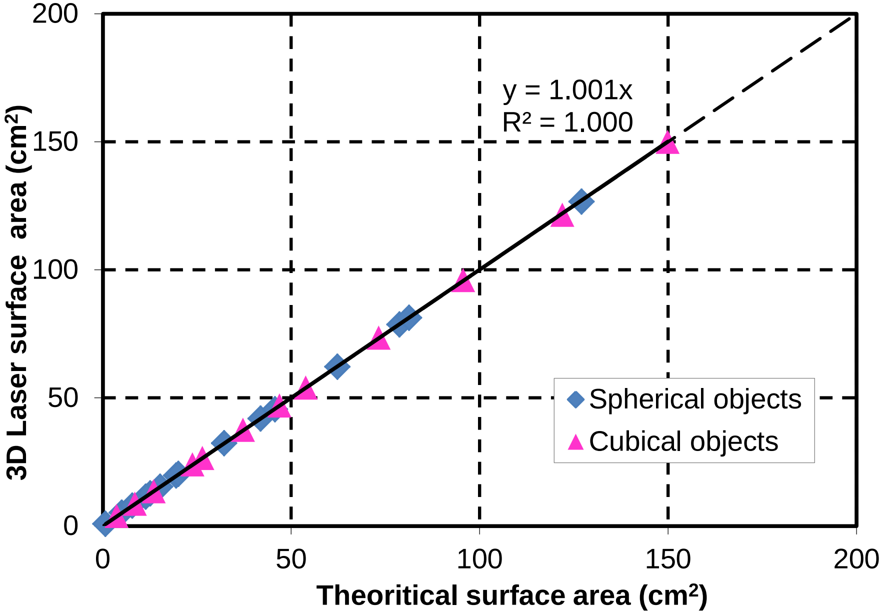
$$Angularity\ index = \sum_{l=n_1+1}^{n_2} \sum_{m=-l}^{l} |a_{lm}|$$

***x, y, z* coordinates of modelled aggregates & centre of mass coordinates**

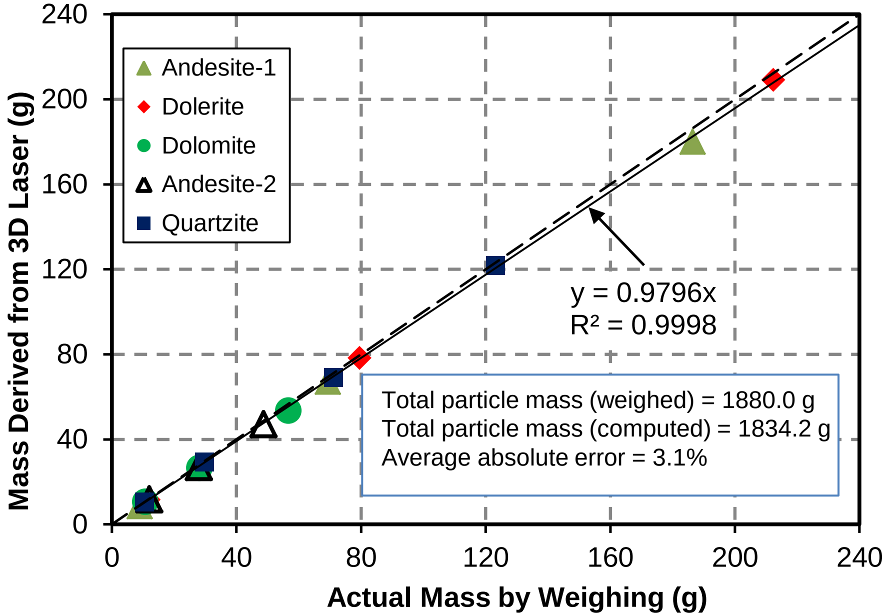
Surface texture

$$Texture\ index = \sum_{l=n_2}^{l_{max}} \sum_{m=-l}^{l} |a_{lm}|$$

Surface Area & Volume Validation

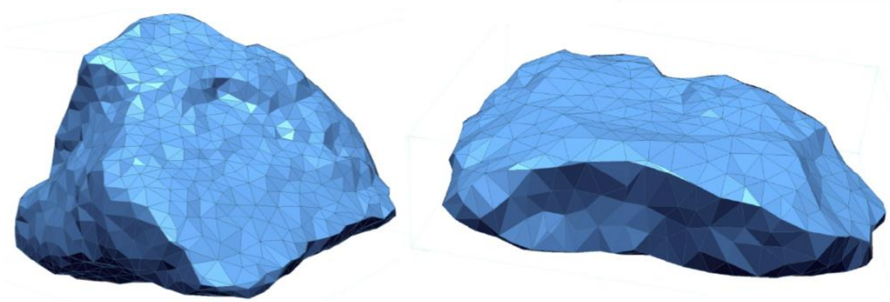


ASTM Journal of Transportation Engineering 2012



Journal of Construction & Building Materials 2013

Surface Area & Volume Validation



(a) 3-D Equi-dimensional particle
No. of poly-faces = 2566
Surface area = 2045 mm²
Volume = 6241 mm³

(b) 3-D flat/flaky particle
No. of poly-faces = 1040
Surface area = 1456 mm²
Volume = 2903 mm³

$$SA_T = \sum_{i=1}^{N} A_i = A_1 + A_2 + A_3 + \cdots + A_N$$

$$Area = \frac{1}{2}\sqrt{\left|det\begin{pmatrix} x_A & y_A & 1 \\ x_B & y_B & 1 \\ x_C & y_C & 1 \end{pmatrix}\right|^2 + \left|det\begin{pmatrix} y_A & z_A & 1 \\ y_B & z_B & 1 \\ y_C & z_C & 1 \end{pmatrix}\right|^2 + \left|det\begin{pmatrix} z_A & x_A & 1 \\ z_B & x_B & 1 \\ z_C & x_C & 1 \end{pmatrix}\right|^2}$$

Poly-face no.	Area of principal planes			Poly-face Area		Difference
	Area XY $\times 10^{-6}$ (mm²)	*Area YZ* $\times 10^{-6}$ (mm²)	*Area ZX* $\times 10^{-6}$ (mm²)	Pythagorean *Area* $\times 10^{-6}$ (mm²)	Laser *Area* $\times 10^{-6}$ (mm²)	*Area* $\times 10^{-6}$ (mm²)
1	169.2354	493.0536	230.9698	14943.72	14943.74	-0.02
2	191.9350	1395.7502	374.8352	22150.17	22145.81	4.36
3	391.7549	1013.1871	138.1201	19640.91	19642.67	-1.76
4	204.0647	370.0068	73.7443	12726.11	12727.96	-1.85
5	1133.7160	1088.4338	714.1107	27093.64	27089.92	3.72

$$V = \frac{\left|(\boldsymbol{a}-\boldsymbol{d})\cdot\left((\boldsymbol{b}-\boldsymbol{d})\times(\boldsymbol{c}-\boldsymbol{d})\right)\right|}{6} \qquad V_T = \sum_{i=1}^{N} V_i = V_1 + V_2 + V_3 + \cdots + V_N$$

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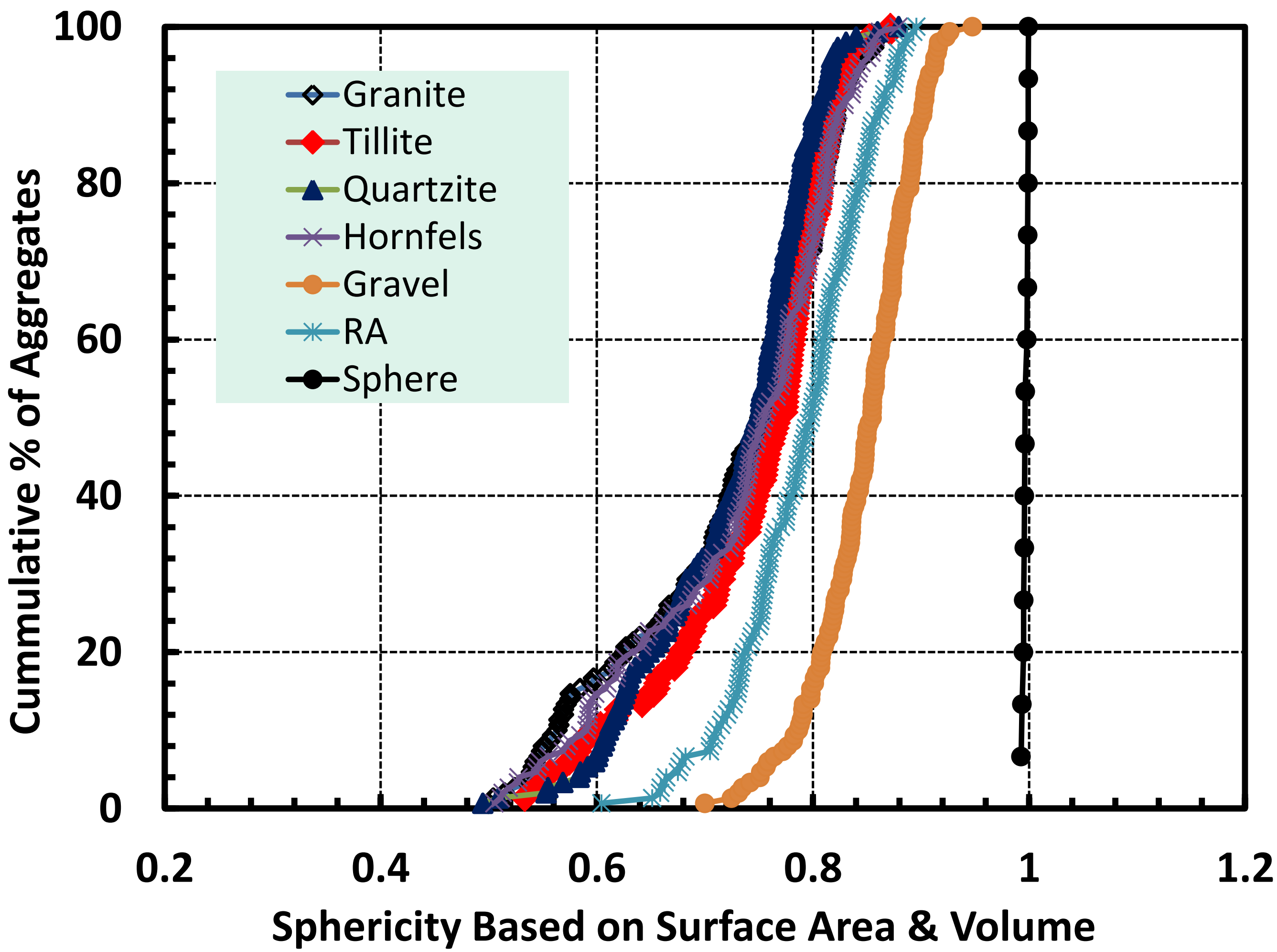
Shapes Differentiation by 3D Laser



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Applications in Asphalt Mix Design

Aggregate particle size (mm)	Surface area factors (m^2/kg) TRH8, MS-4	3D Laser based surface area factors (m^2/kg) CSIR
19	0.41 (Hveem, 1942..!)	**0.13**
13.2		**0.18**
9.5		**0.24**
6.7		**0.31**
4.75		**0.43**

Journal of Trans Eng © ASCE / August 2012

Sieve Sizes (mm)	Surface Area Factor (m^2/kg)
26.5	0.41
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4.75	0.41
2.36	0.82
1.18	1.64
0.600	2.87
0.300	6.14
0.150	12.29
0.075	32.77

SA = 0.41 + 0.41*a* + 0.82*b* + 1.64*c* + 2.87*d*+ 6.14*e* + 12.29*f* + 32.77*g*

SA′ = 0.13*a′* + 0.18*b′* + 0.24*c′* + 0.31*d′* + 0.43*e*‘+ SA

$$SA = \frac{1}{100}\sum PC$$

$$T_F = \frac{V_{asp}}{SA \times W}(1{,}000)$$

$$B_{PCC} = K \times \alpha \times \sqrt[5]{SA}$$

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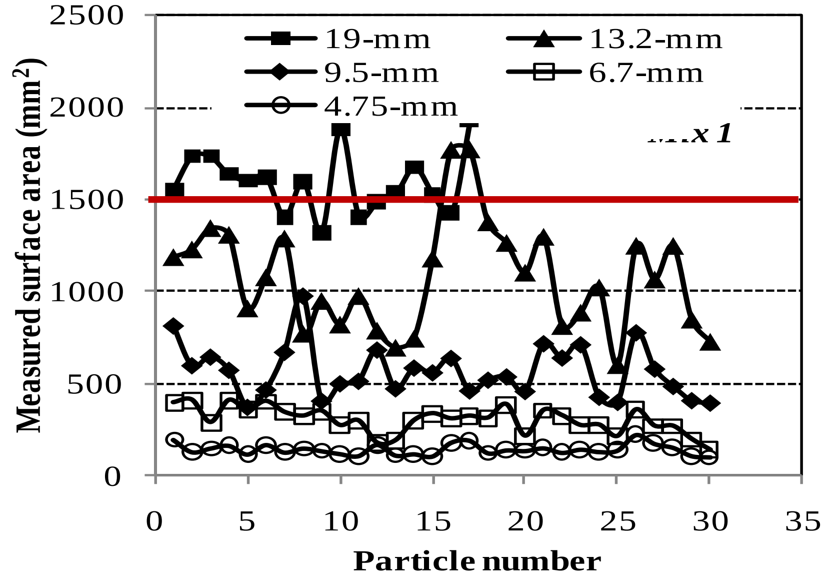
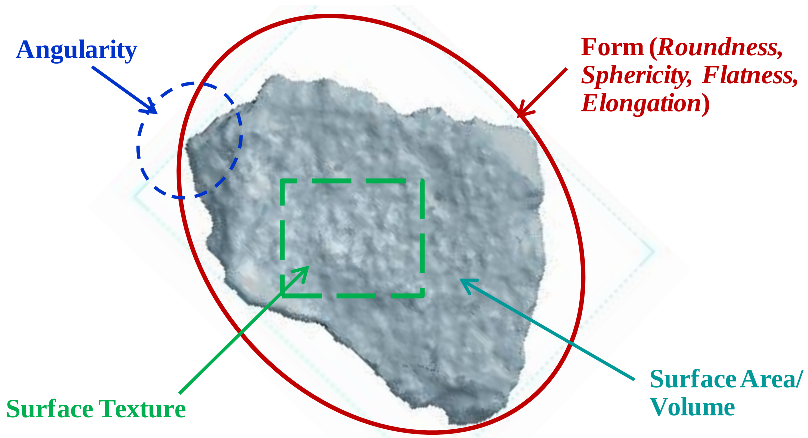
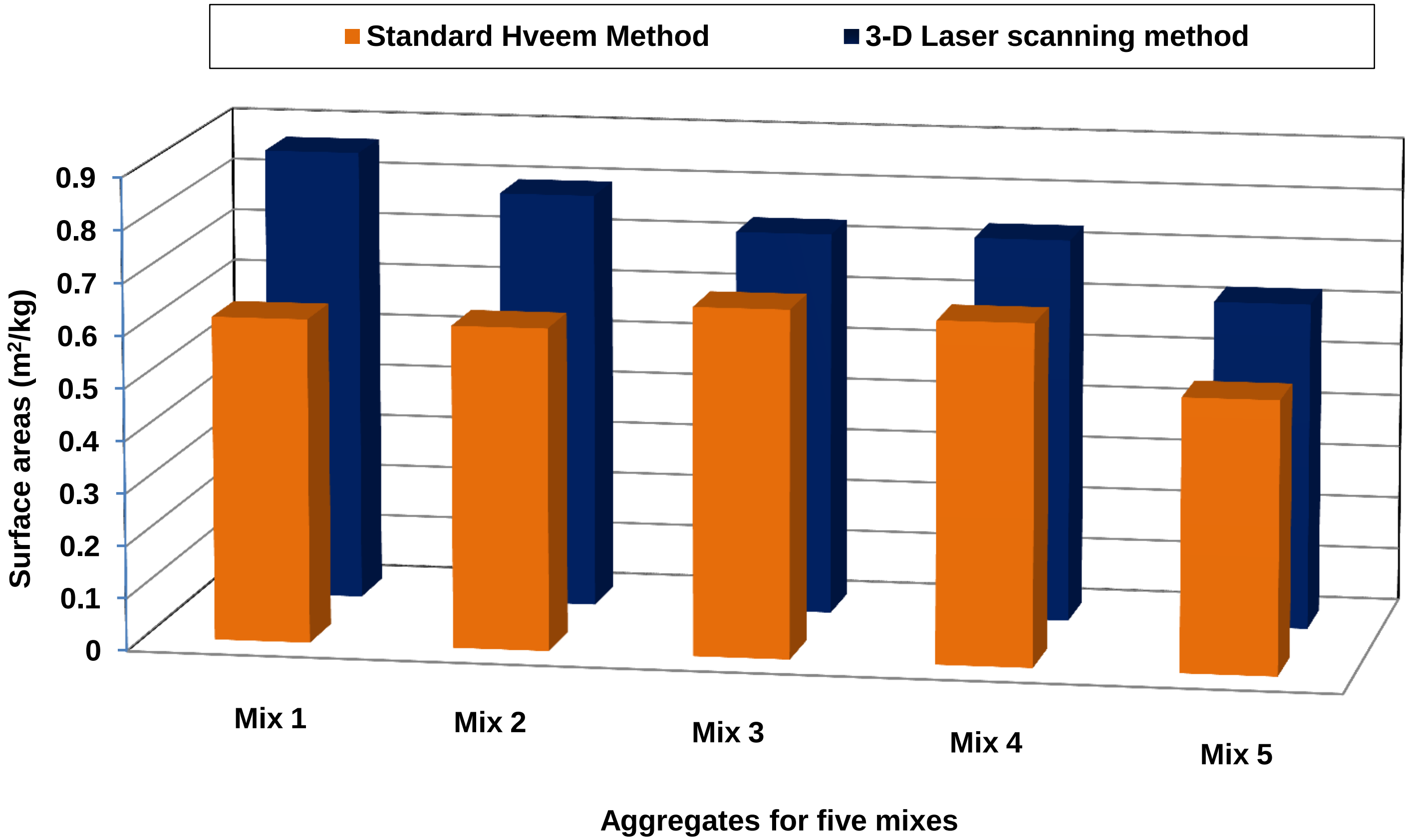
Applications in Asphalt Mix Design





Applications in Asphalt Mix Design



*…For those of you with an interest in 3D, an article submitted by the CSIR "**Laser-based approach for determining surface area of aggregates used in asphalt mixes**" will be of significance, particularly as the traditional Hveem method has been the only other method used…***Saied Solomons, Sabita CEO, 2012***

Laser-based approach for determining surface area of aggregates used in asphalt mixes

Dr JK Anochie-Boateng
CSIR Built Environment, Pretoria

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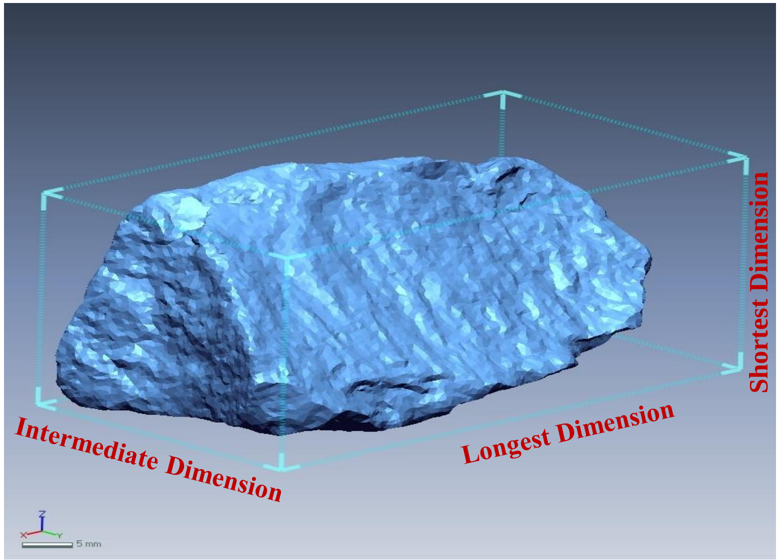
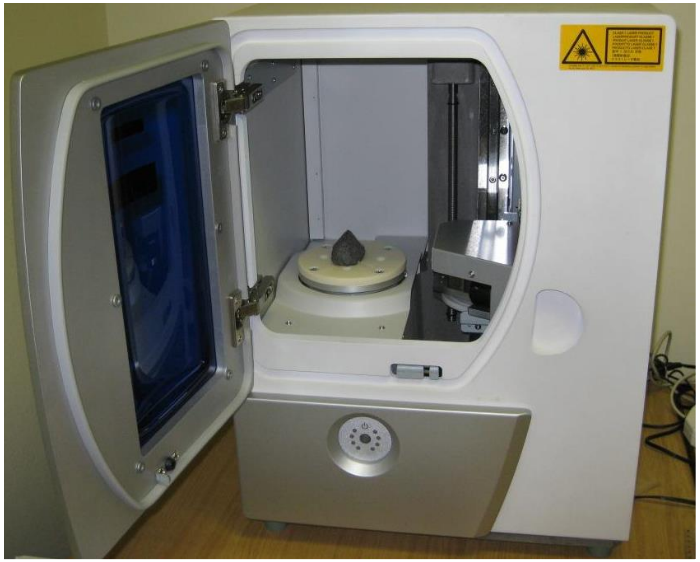
Applications in Asphalt Mix Design





Applications in Asphalt Mix Design

Material type	TMH 1 Method	3-D Laser method	Difference
Granite	28.1	24.1	4.0
Tillite	21.8	21.2	0.6
Hornfels	29.9	29.3	0.6
Quartzite	36.4	35.3	1.1
Dolerite	18.4	14.9	3.5
Andesite	29.6	23.4	6.2
Alluvial gravel	3.1	5.5	-2.4
Dolerite (Recycled ballast)	3.1	2.9	0.2
Dolerite (Fresh ballast)	20.2	13.8	6.4

Flakiness Index

$$FI = \left(\frac{M_p}{M_T}\right) \times 100$$

$$FI_v = \left(\frac{V_p}{V_T}\right) \times 100$$

Aggregate Type	F&E Ratio (%) for 2:1		F&E Ratio (%) for 3:1		F&E Ratio (%) 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
RA	60	49	15	11	0	0

Flat & Elongated particles ratio

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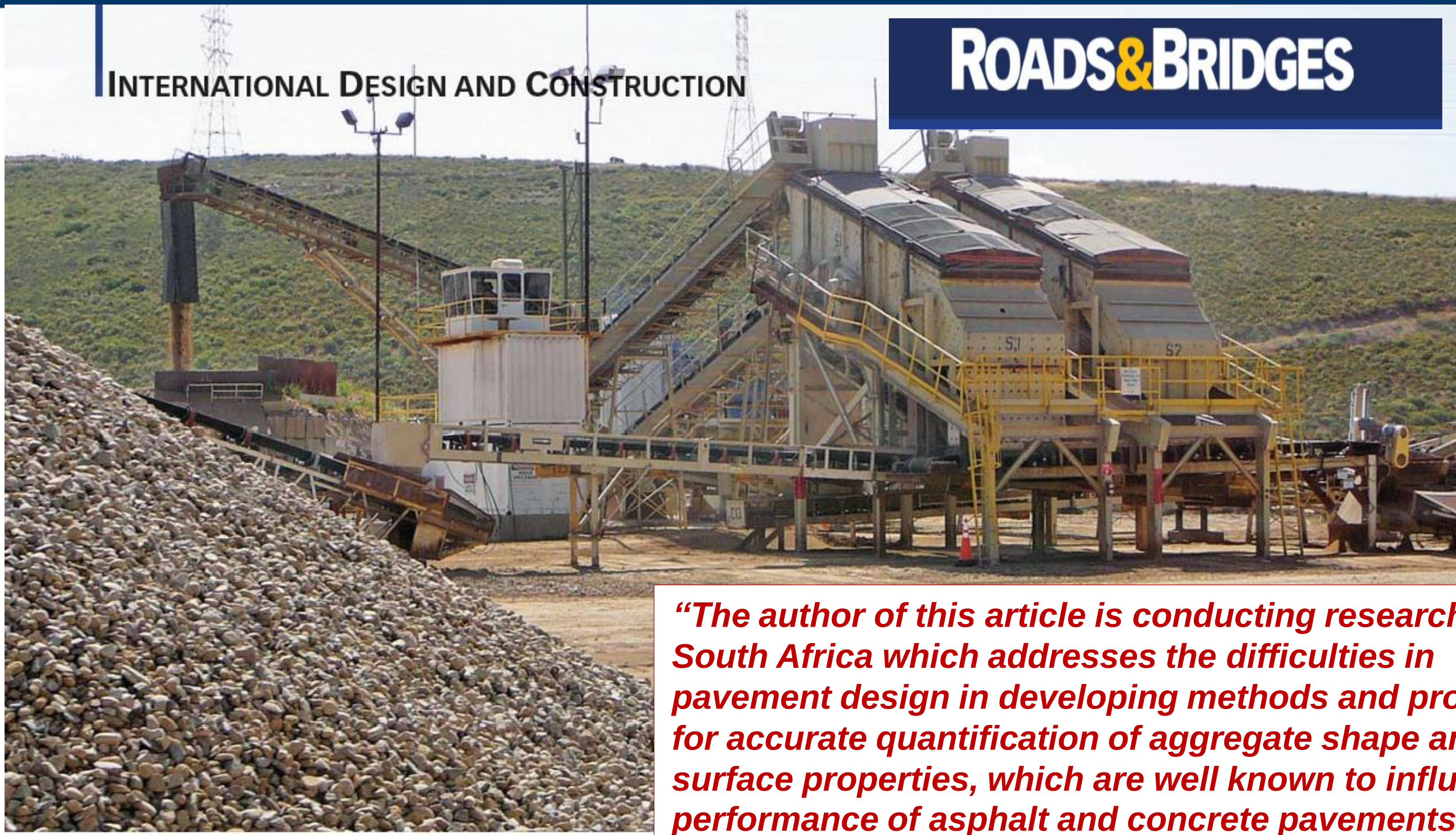
Publication Highlight

INTERNATIONAL DESIGN AND CONSTRUCTION

ROADS&BRIDGES



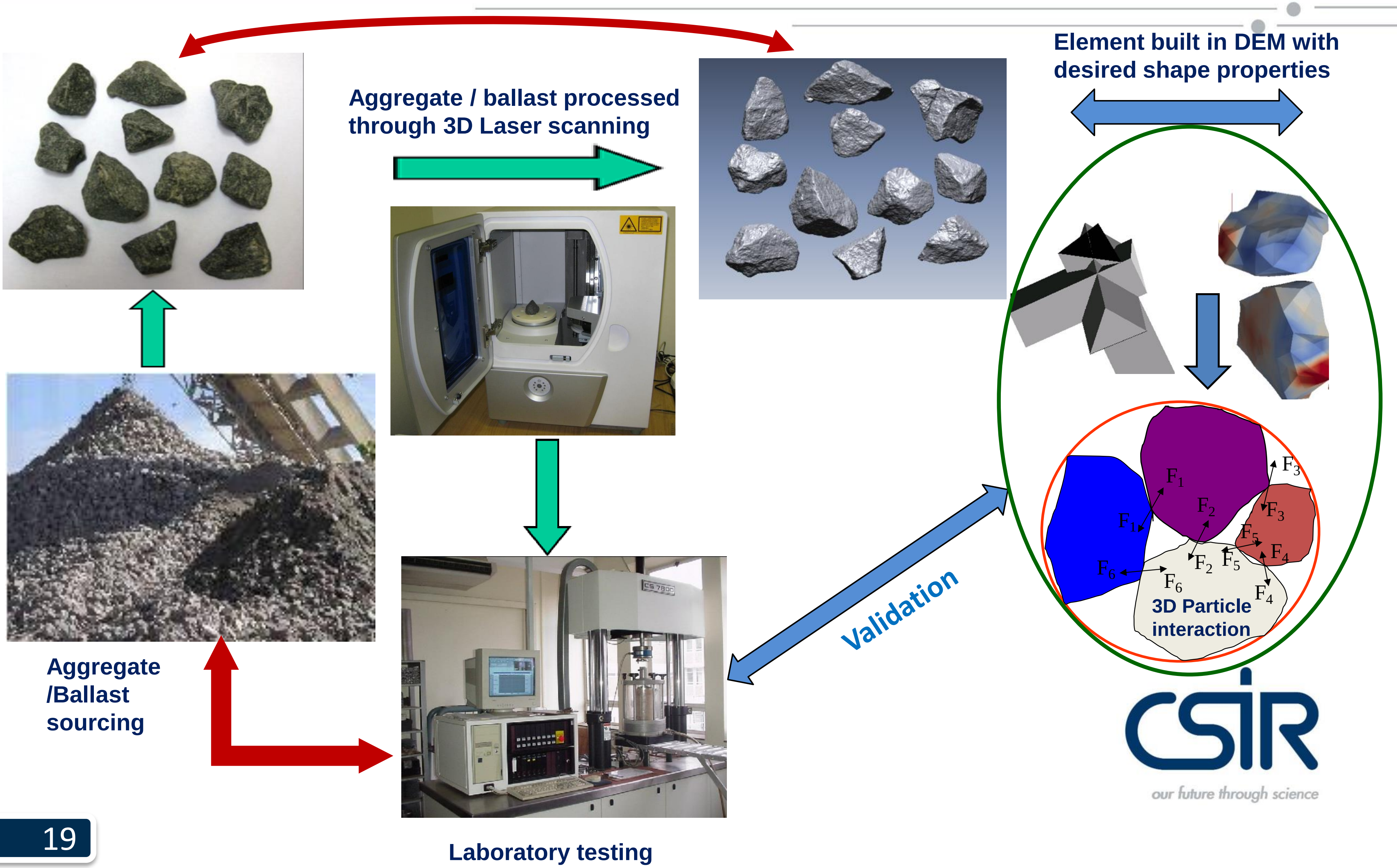
"The author of this article is conducting research in South Africa which addresses the difficulties in pavement design in developing methods and procedures for accurate quantification of aggregate shape and surface properties, which are well known to influence the performance of asphalt and concrete pavements." 2012

By Joseph K. Anochie-Boateng, Ph.D.
Contributing Author

The best of shape

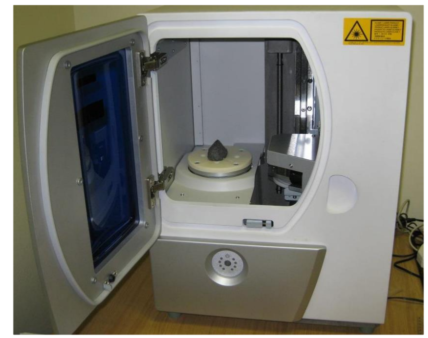
3-D scanning in S. Africa gives aggregate a closer look

Summary of 3D Laser R&D at CSIR

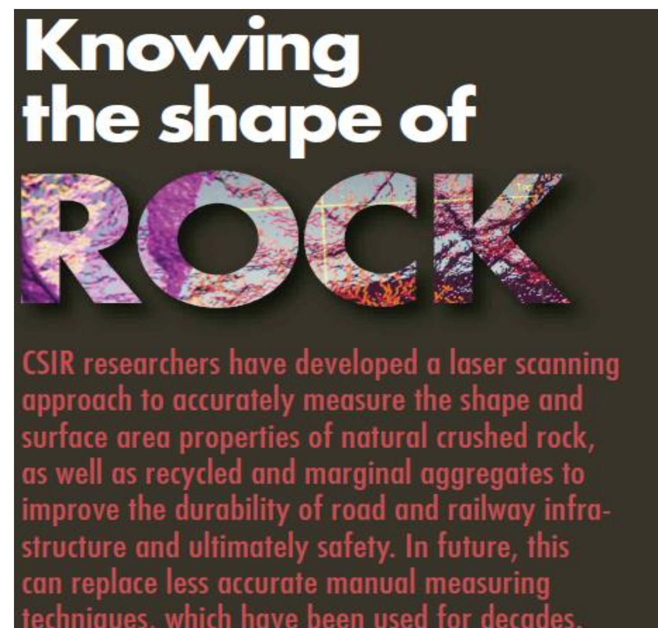


Conclusions

- The 3D laser scanning approach has demonstrated that there are limitations in the current standard methods and specifications of aggregates used in pavements
- 3D laser is an appropriate tool improve the current specifications of aggregates
- A tool for establishing aggregate shape properties database to efficiently rank aggregate obtained from different crushers



Without proper modelling of aggregate materials, roads can deteriorate to such an extent that it incurs increased or unforeseen spending on infrastructure and even fatal road accidents


Knowing the shape of ROCK

CSIR researchers have developed a laser scanning approach to accurately measure the shape and surface area properties of natural crushed rock, as well as recycled and marginal aggregates to improve the durability of road and railway infra-structure and ultimately safety. In future, this can replace less accurate manual measuring techniques, which have been used for decades.

Thank you

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