PARTICLE SIZE AND SHAPE – IMPORTANT FACTORS FOR PACKING DENSITY

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TOPICS

1. Definitions of particle size and shape and bulk density
2. Packing density - state of the art
3. Measuring methods
4. Results

Particle size

A non spherical particle has many dimensions. Which dimension is measured as particle size depends on:

- the measuring method
- the characteristic particle feature and
- the particle morphology

Each measuring method has an own definition!

Basically the particle size is defined as the equivalent diameter of a ball, which has the same measuring effekt like the real particle.

Particle shape

Fundamental definitions:

- Ratio of particle length to particle width and the resultant fraction

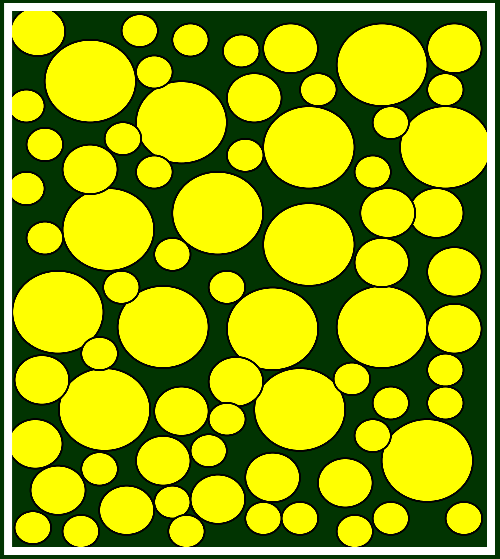
$$L/W$$

- Sphericity as ratio of measured circumference of particle projection and the circumference of a circle of the same area

$$SPHT = \frac{U}{2 \cdot \sqrt{\pi \cdot A}}$$

Packing density

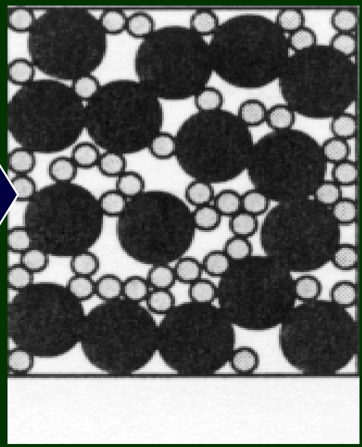
- Total volume V_t = solid volume V_s + void volume V_v
- Void porosity $\varepsilon = V_v / V_t$
- Packing density $\Phi = V_s / V_t$
- Unit mass $\rho_{um} = \Phi \cdot \rho_{particle\ bulk\ density}$



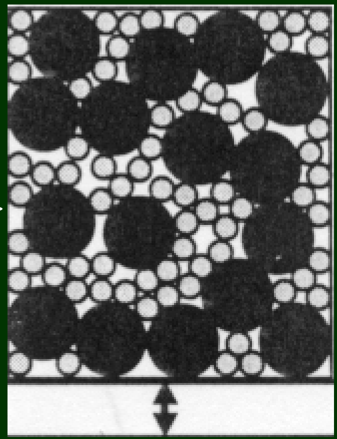
Conditions of measurement influence void porosity and packing density!

Packing density - conditions of measurement

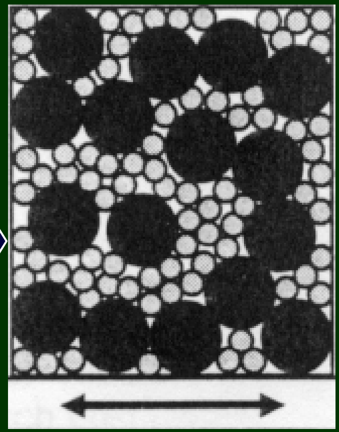
Loose packing density:
The granular material is filled in a defined volume without any compaction.



Tap density:
The granular material is compacted by shocks.



Vibrating density:
The granular material is compacted by vibration.



Early works about packing density

Experimental and theoretical approaches to find grading curves of aggregates with a minimum of voids

Fuller and Thomson	1907	Grading curve with a minimum of voids determinated by experimental work
Furnas	1931	Packing theory for sphere shaped particles
Andreasen and Andersen	1930	Packing density of ceramic materials
Manegold	1955	Packing density in geotechnical appli-cations

Early works about packing density

Experimental and theoretical approaches to find grading curves of aggregates with a minimum of voids

Fuller and Thomson	1907	$Q = (x/x_{max})^m$; $m = 0,5$
Furnas	1931	Base of model: Small particles fill out the cavities between the big particles without disturbing the packing of the big particles.
Andreasen and Andersen	1930	Packing density of ceramic materials
Manegold	1955	Packing density in geotechnical appli-cations

2. Packing Density

Works in the „pre computer“ age

- Broadening and deepening of the earlier approaches
- Development of models for random packing of spheres
- Empirical consideration of influence of shape

Hummel	1959	Experimental determination of void porosity of aggregates. Parameters: Fuller exponent and the particle shape.
Schwanda	1959	Calculation scheme on basis of void porosity of single sized spheres consi-dering interactions between particles. Parameters: Fuller exponent and empi-rically characterized particle shape.

Works in the „pre computer“ age

Peronius and Sweeting	1985	Empirical equation of void porosity as function of Fuller exponent, particle shape and compaction. Shape charac-terized by Powers’ scale of roundness.
Aberg	1992	Empirical equation of void porosity of any particle size distribution as function of particle shape. Shape characterized empirically.
Yu, Standish, and Zou	1993 1997	Theoretical model of void porosity for continuous or mixed single-sized distributions of different shape. Experimental calibration necessary.
Tsirel	1997	Empirical equation of void porosity of particle size distributions acc. to Fuller as function of particle shape.

Works in the „computer“ age

- Numerical modeling of packing density of spheres
- First analytical consideration of influence of shape

Stovall et al., Glavind et al.	1986 1999	Model on basis of packing of binary mixtures, extended to multi-sized mixtures. Inclusion of experimentally determined packing densities.
De Larrard	1999	Packing model of multi-sized granular materials considering interactions between the particles and wall effects. Experimentally determined parameters included.

2. Packing Density

Works in the „computer“ age

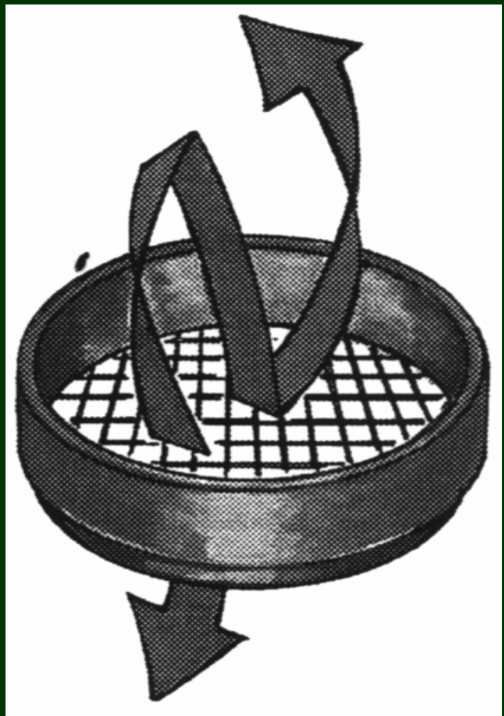
Stroeven and Stroeven	1999	DEM-simulation of dense random packs of spheres with different size distributions.
Stoyan et al.	2001	Spatial-statistical analyses for simulated random packings of spheres with random diameters
Latham et al.	2001	Space filling tetrahedron assembly model and dynamic interaction model for real-shaped particles.

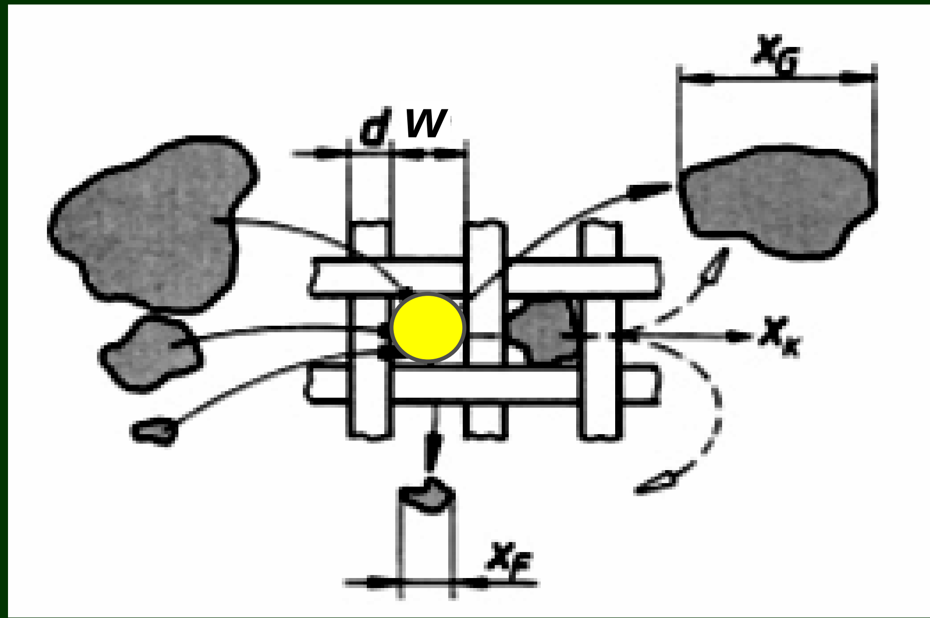
Comparison of “gravel” and “crushed aggregates” acc. to different measurements and models:

$\Delta = 100 \cdot (\varepsilon_{gravel} - \varepsilon_{crushed\ aggregates}) / \varepsilon_{crushed\ aggregates}$

	ε		Δ	
	“gravel”	“crushed Aggr.”		Compared at
Hummel	0,188	0,235	22 %	ε = min
Schwanda	0,132	0,244	46 %	ε = min
Peronius	0,130	0,235	45 %	m = 0,5 = const
Tsirel	0,176	0,217	19 %	m = 0,5 = const
Latham	0,374	0,568	34 %	ε = min

Sieving method





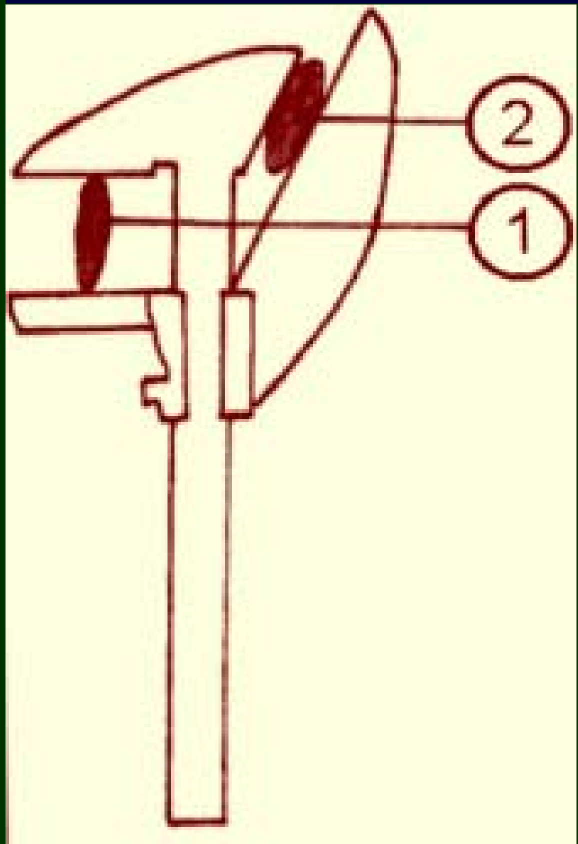
Geometrical comparison between particle size and sieve aperture

Particle size = equivalent ball diameter with size of mesh w

Particle shape with gauge method – Shape Index SI

Measurement based on the funda-mental definition:
ratio Length to Width

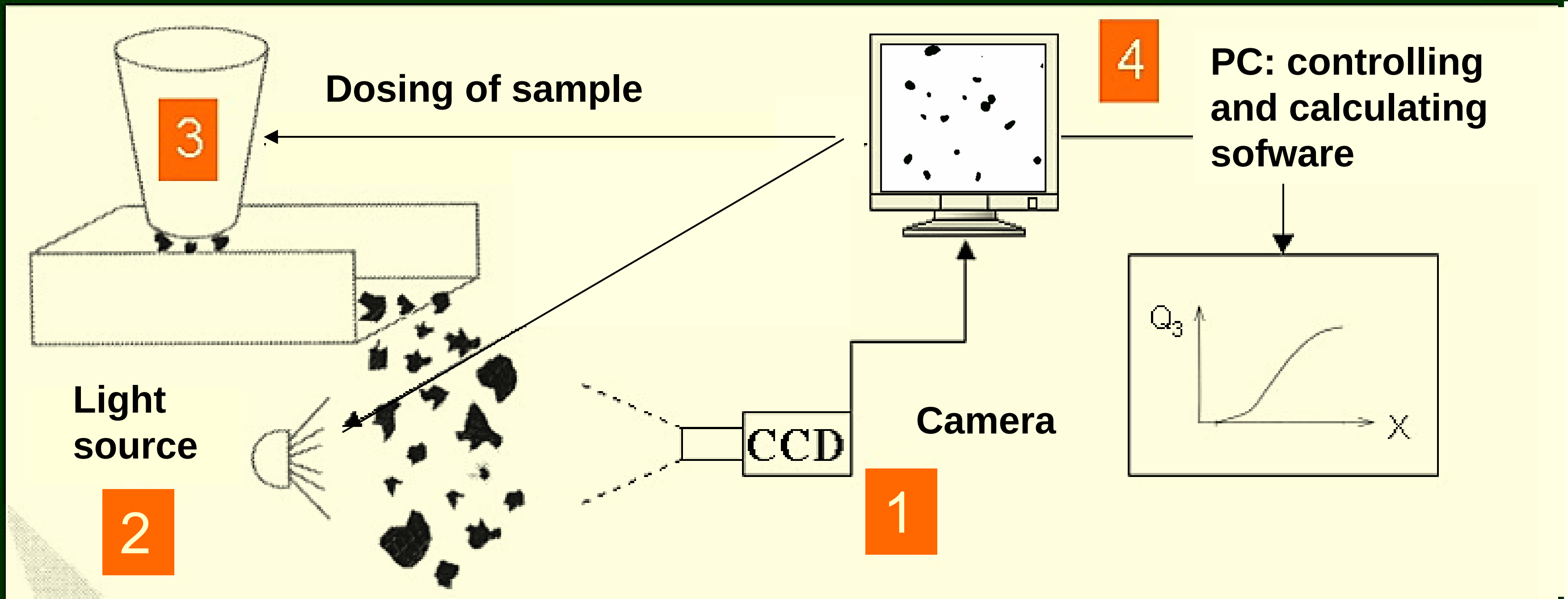
$SI = (M_2/M_1)\ 100$



1. Ratio of sizes of gauge: Length / Width = 3/1
2. Separating of all grains with L / W > 3
3. Weighing:
   M_1 - Mass of complete sample / Gramm
   M_2 - Mass of non-cuboid grains / Gramm

Amount of total sample:
Minimum 300 Grains per fraktion

Particle size and shape with photo-optical method

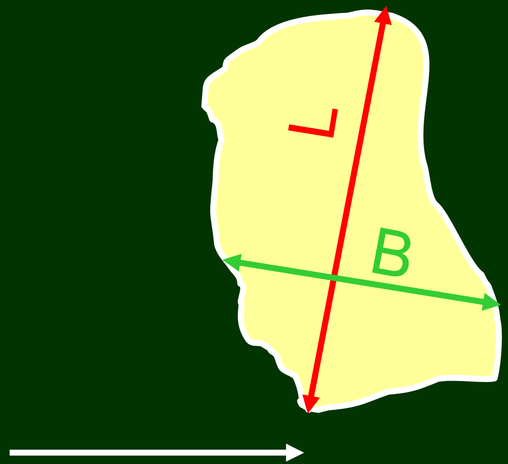


Schematic structure of a photo-optical particle size and shape analyser.

The used device: HAVER CPA 4-2 real time

Particle size and shape dimensions

Shadow projection



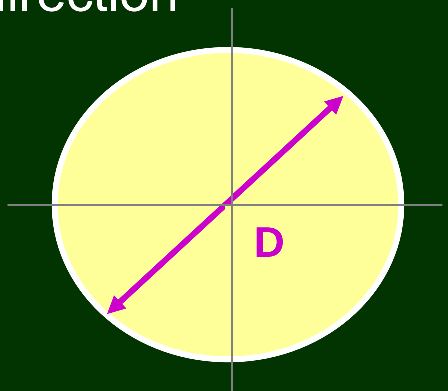
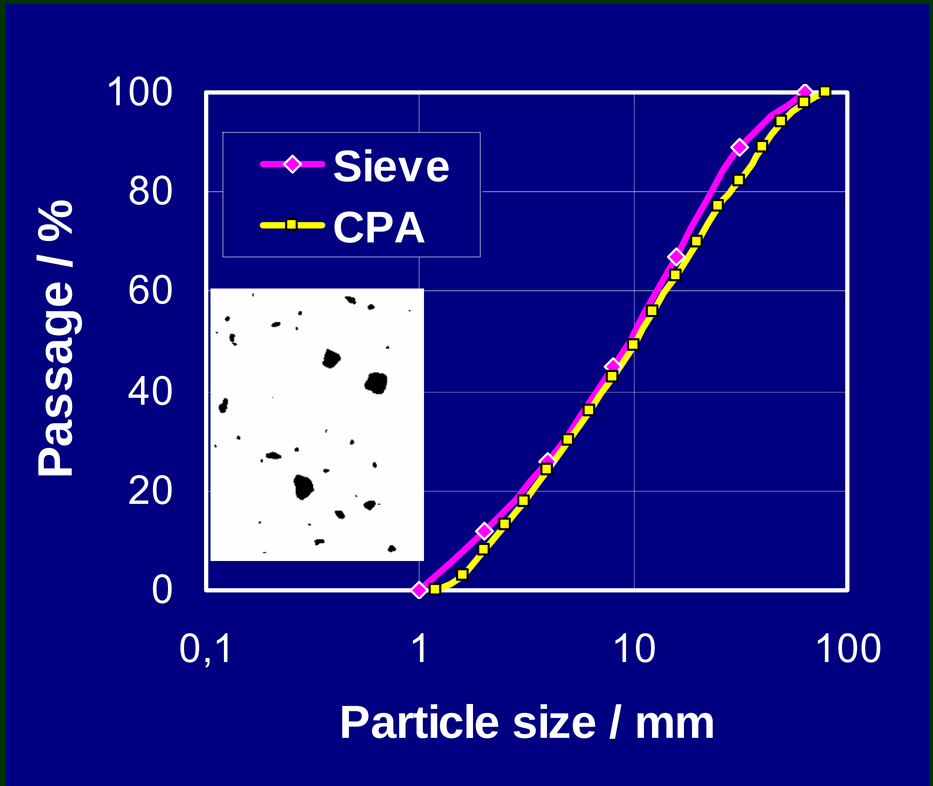


Image analyses

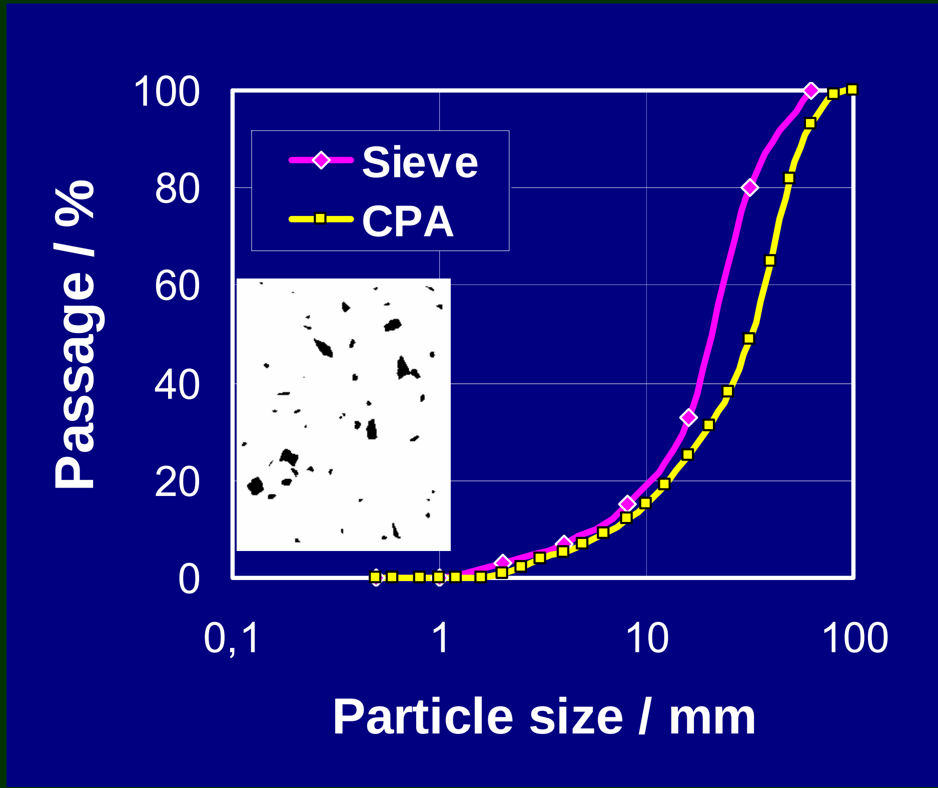
- Circumference U
- Area A of projection
- Largest Length
- Largest Width

Particle size = Diameter of circle with the same area like the projection area A

Comparison particle size distributions: sieve and CPA analyses

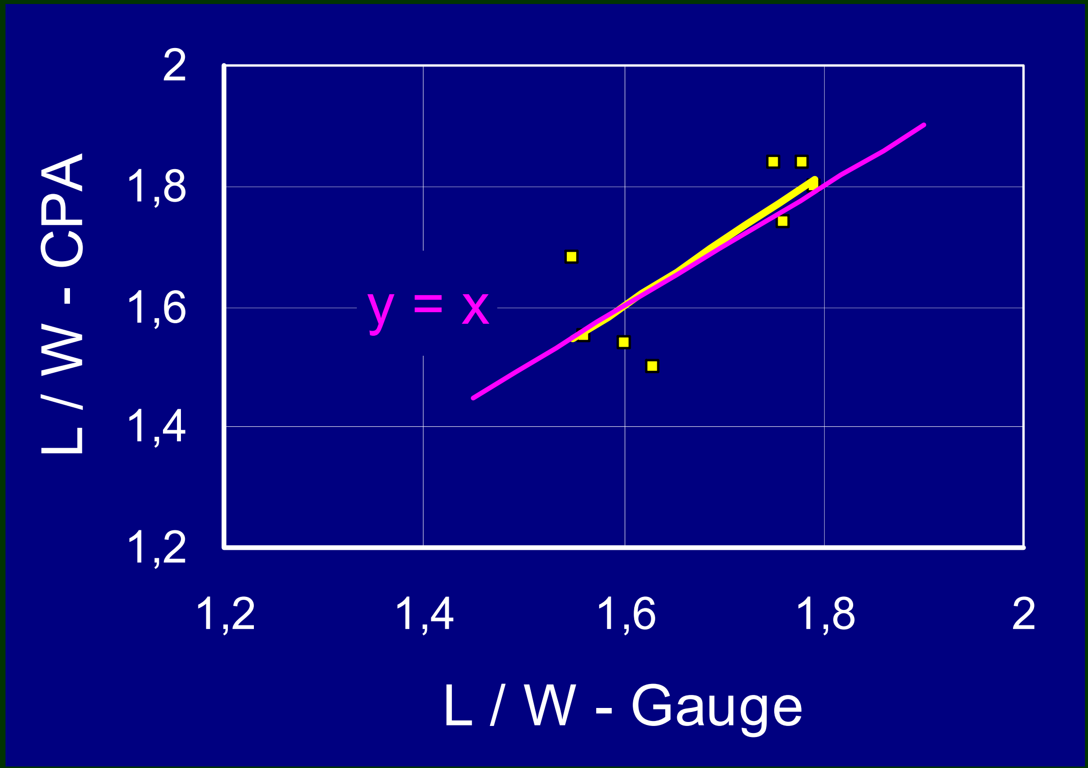


Cuboid particles



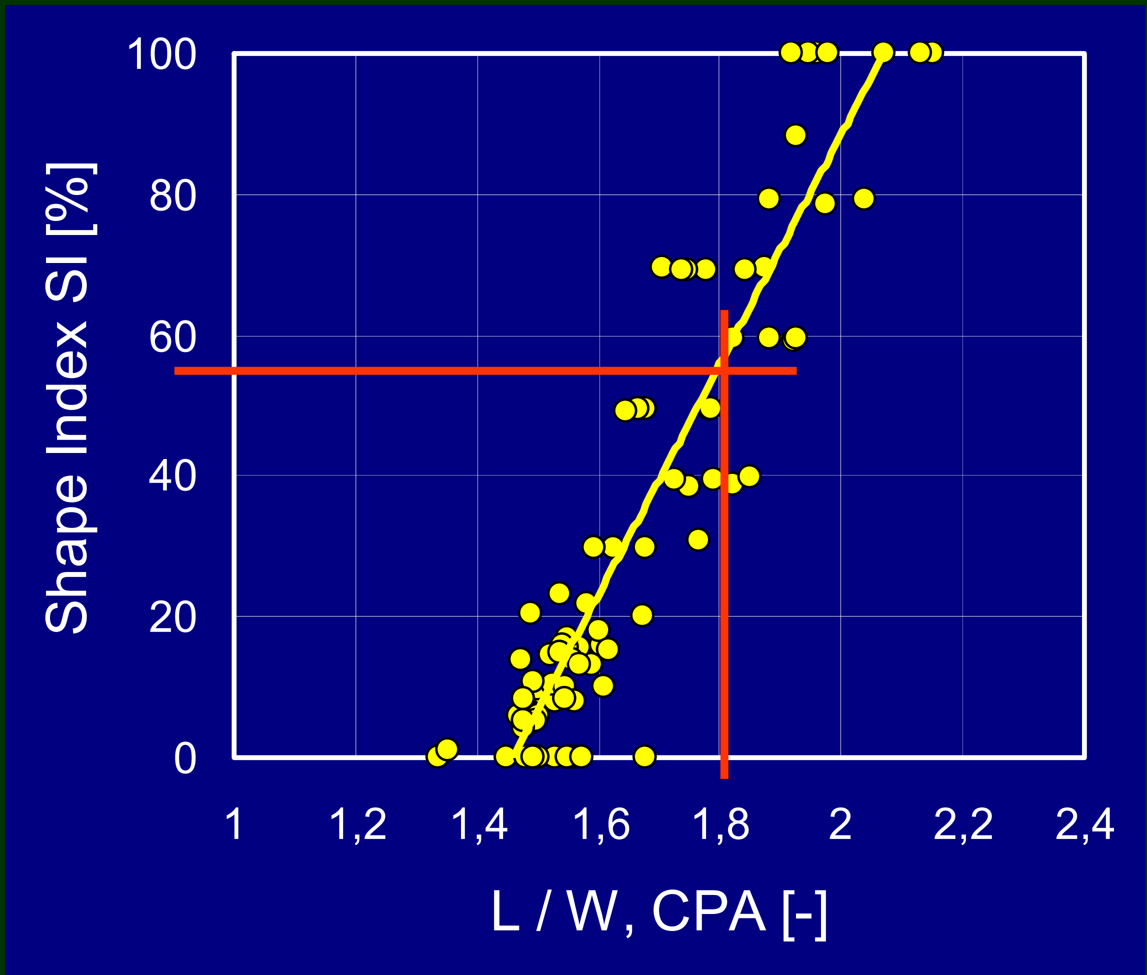
Gritty to flaky particles

Comparison particle shape results: gauge and CPA analyses



In both cases mean sizes of L/W- Parameters based on number distribution

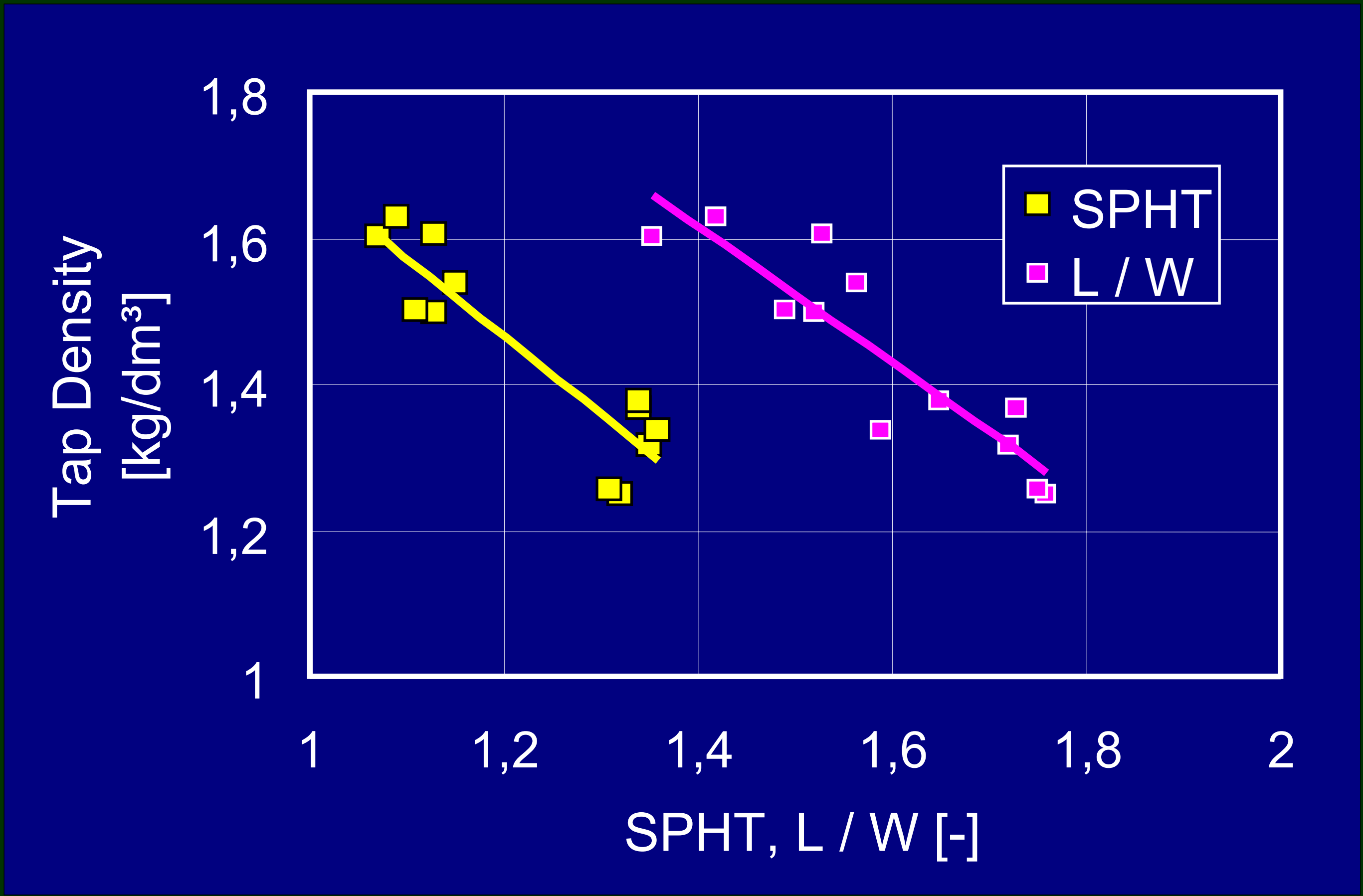
Correlation - shape parameters L / W and SI



Analysed both natural and crushed aggregate fractions and also modelling fractions by shape

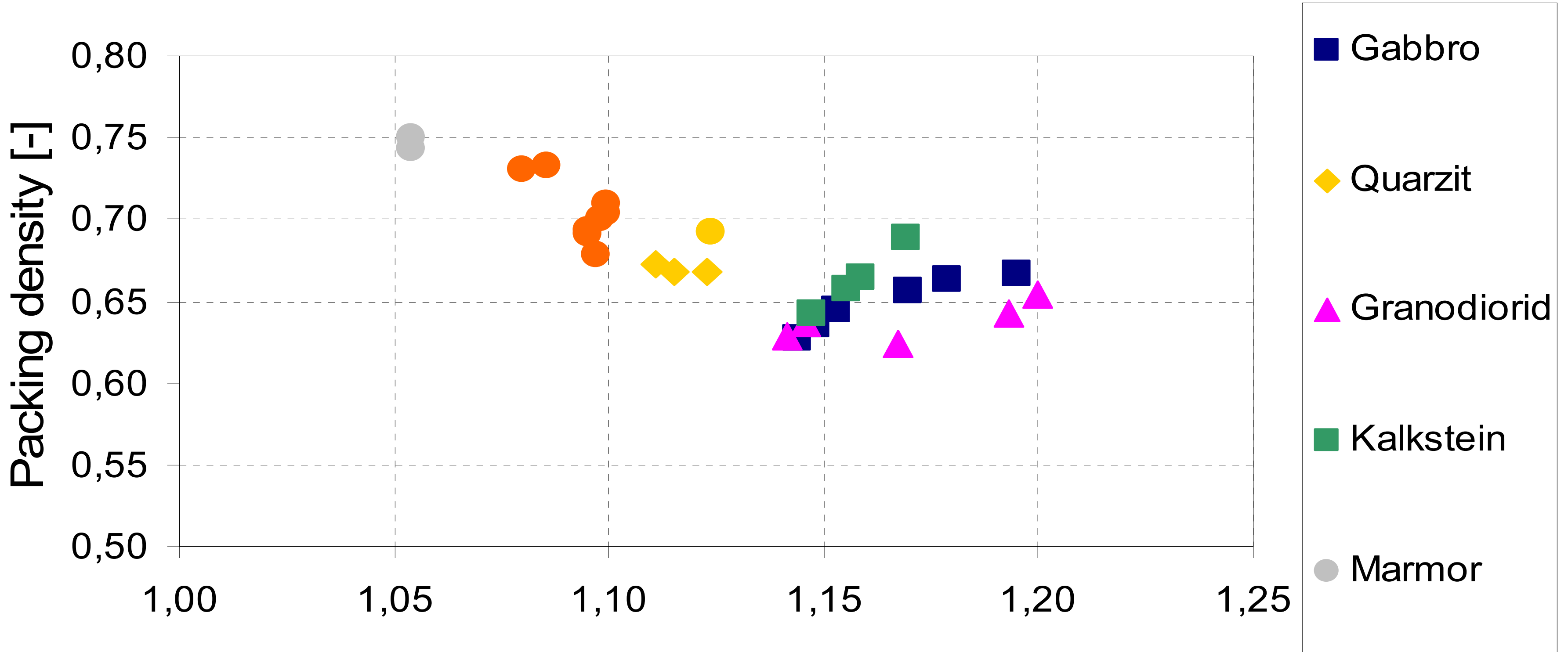
L / W – mean: calculation based on volume distribution

Tap density in comparison with particle shape



Analysed fractions with different shape and size:
8/16 mm
16/32 mm
8/32 mm.

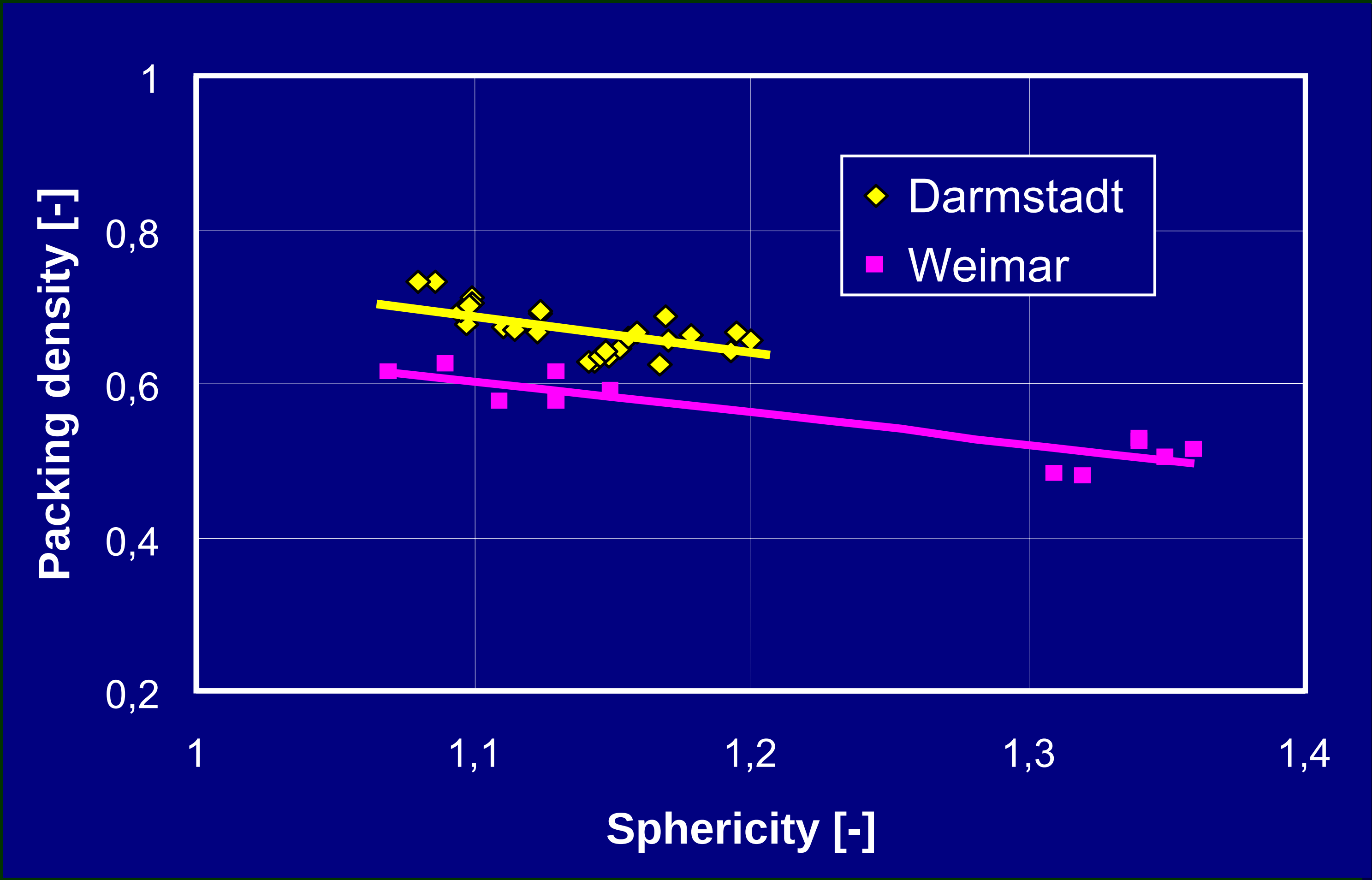
Influence of particle shape on packing density



Authors: Graubner / Proske / Ramge, TU Darmstadt

5. Results

Influence of particle shape on packing density



Darmstadt:

Gabbro

Quarzit

Granodiorit

Kalkstein

Marmor

Rheinkies

Weimar:

Kalkstein

CONCLUSIONS

- **Simulation models:**

  Mostly balls are considered. Large differences between the results are obtained.

- **New photo-optical measuring methods:**

  Particle size and particle shape can be determined quantitatively.

- **Influence of particle shape:**

  First measuring results of relationship between

  - SI-Index and photo-optical measured L / W ratio
  - Packing density and L / W ratio and SPHT

OUTLOOK

- Future works:

Investigations and experiments about the influence of particle shape on all relevant properties of bulk materials.

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