THE ABILITY OF GRAIN SIZE AND SHAPE TO CHARACTERISE SILICICLASTIC, CARBONATE AND MIXED SEDIMENTS

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Abstract

Grain size is commonly used to indicate sediment source, transport, erosion and deposition trends. However, a representative multi-parameter approach is essential to accurately predict the dynamics of coastal sediments. Coastal sediments commonly contain bioclastic carbonate (shell) as well as siliciclastic components. Sediments components vary greatly by location and within the same beach systems. This study investigates the representative ability of grain size and shape to distinguish between siliciclastic, carbonate and mixed siliciclastic-carbonate sediments. Pure carbonate (PC) sediments were collected from One Tree Reef (southern Great Barrier Reef), and mixed sediments (MS) were collected from Sydney's eastern embayed beaches. Pure siliciclastic (PS) samples were created from our MS samples by dissolving the carbonate component with hydrochloric acid. Grain size distribution, mean and median sizes were obtained from settling tube and laser particle analyses and grain shape by Malvern Morphologi G3 (MG3) analysis. Here we show that shape has a more significant influence on sediment grain size than bulk density. Primer cluster analyses showed similarities between grain size parameters for PS (~88%) and MS (~90%) sediments. However, PC mean and median grain sizes were different from the others (~60%) due to their heterogeneous shape and density. Thus, mean and median grain size are representative for PS and MS sediments. However, this is not the case for PC sediments. We also explored solidity density, based on bulk density and sediment solidity. Using solidity density for the PC sediments we found that mean grain size correlated with other grain size parameters. Thus, our results show for the first time that mean grain size, based on solidity density, was able to represent PC sediments. Findings from this study will ultimately assist quantification of sediment response to hydrodynamic pressures and aid in model predictions for beach monitoring along coastal sediment systems with varied sediment components.

Introduction and background

Sediments and waves are key factors for the formation of beaches, no matter how beaches are defined (Short, 1999). Beach morphodynamics not only includes beach morphology, hydrodynamic process and sediment transport, but also indicates the interaction and feedback among all these components (Wright and Thom, 1977).

Consequently, sediment, as a significant factor of beach and sediment transport, deserves profound study for thoroughly understanding and explaining of the beach morphodynamics.

Particle properties, including grain size, grain size distribution, shape and bulk density, are commonly measured and discussed to describe and analyse sediments. Among all the textural parameters, grain size is the most significant because it indicates the nature of source rocks or materials and the resistance of the particles to the process of weathering, transportation, deposition and erosion (de Lange et al., 1997). Consequently, various definitions and calculations of mean grain size or median grain size by different experimental methods are proposed to represent the grain size of sediment appropriately (Folk and Ward, 1957, Smith and Cheung, 2002). Various methods can be used to analyse sediments, including sieving, settling tube, laser particle analysis (LPA) and imaging techniques (such as Malvern Morphologi G3, MG3), depending on the characteristics of sediments and purpose of determination of grain size and distribution (Rodríguez and Uriarte, 2009).

Numerous studies have estimated the grain size of siliciclastic sediment by different techniques, including sieving and settling-tube, which turn out that small differences are found in the results of the various methods due to the relatively uniform density and shape of siliciclastic sediments (Kench and McLean, 1997). However, some studies indicate the divergence in grain size measurement of siliciclastic sediments with varying density or components (de Lange et al., 1997, Komar and Cui, 1984), which illustrates that mean grain size are probably only representative for sediments with uniform density and shape.

Studies using carbonate sediments found that the results of grain size of carbonate sands were significantly different depending on the measuring methods (de Lange et al., 1997, Maiklem, 1968, Smith and Cheung, 2002). The various shapes and densities of sediments with same size may be the main reason of these different results. Prager et al. (1996) found that carbonate sediment can have varied density and shape, because they come from both organic and inorganic sources. Organic sources, such as coral and crustose coralline algae, may include voids, resulting in the complicated skeletal construction and further influencing bulk density.

Therefore, having a better way to represent the size of carbonate or mixed sediment is important for understanding the hydrodynamic behaviour of sediment and interpreting the processes of entrainment, transport and deposition (Prager et al., 1996). Some attempts have been done to define new parameters to replace mean grain size for representing carbonate sediments. For instance, Smith and Cheung (2002) proposed the median nominal diameter and the median equivalent diameter, however, the need of the particle details made the calculation complicated. Moreover, only few research studies (Mount, 1984, Prager et al., 1996) focus on the situation of mixed siliciclastic-carbonate sediments, which is an extremely common combination in the natural environment.

This study presents a number of experiments using pure carbonate (PC), pure siliciclastic (PS) and mixed siliciclastic-carbonate sediment (MS) to demonstrate that mean grain size or median grain size are representative for siliciclastic sediments, whereas they are not suitable for carbonate sediments. Moreover, two significant heterogeneous characteristics of carbonate sediment, shape and density, are compared and analysed to establish which one plays a more important role on the influence of size measurement. A new density factor combined with shape is used in the calculation of mean grain size to better represent the PC and MS samples.

Study areas

This research uses sediment samples from two study areas, One Tree Reef (OTR), a coral reef located in the southern Great Barrier Reef, and four temperate open-ocean beaches located in eastern Sydney: Bondi, Tamarama, Bronte and Maroubra beach.

One Tree Reef

OTR (23°30'S 152°06'E) (Figure.1B), is a lagoonal platform reef located in the Capricorn and Bunker Groups in the southern Great Barrie Reef (GBR) (Jell and Flood, 1978). Two windward and one leeward subtidal sand aprons are located at southern, eastern and northern side of the largest lagoon of OTR (Figure 1B), respectively, which has 100% carbonate bioclasts generated sediment *in situ* (Vila-Concejo et al., 2014, Vila-Concejo et al., 2013). Compared with the other two sand aprons, the southern sand apron (SSA) is the largest and the most studied. It is found that little progradation has occurred during the last 30 years (Vila-Concejo et al., 2014).

Sydney eastern beaches

The Sydney region has some of the most dynamic beach systems in the world, which are significantly different in beach shape and width (Short and Wright, 1981). The four studied beaches (Figure 1C) are typically intermediate embayed beaches with various exposures and wave energy levels (Barros et al., 2002, Short and Wright, 1981). Due to the dynamic beach system, constantly changing morphology, sediments characteristics and wave energy (Barros et al., 2002), the sediments from these beaches are different with each other in grain size, density and other characteristics.

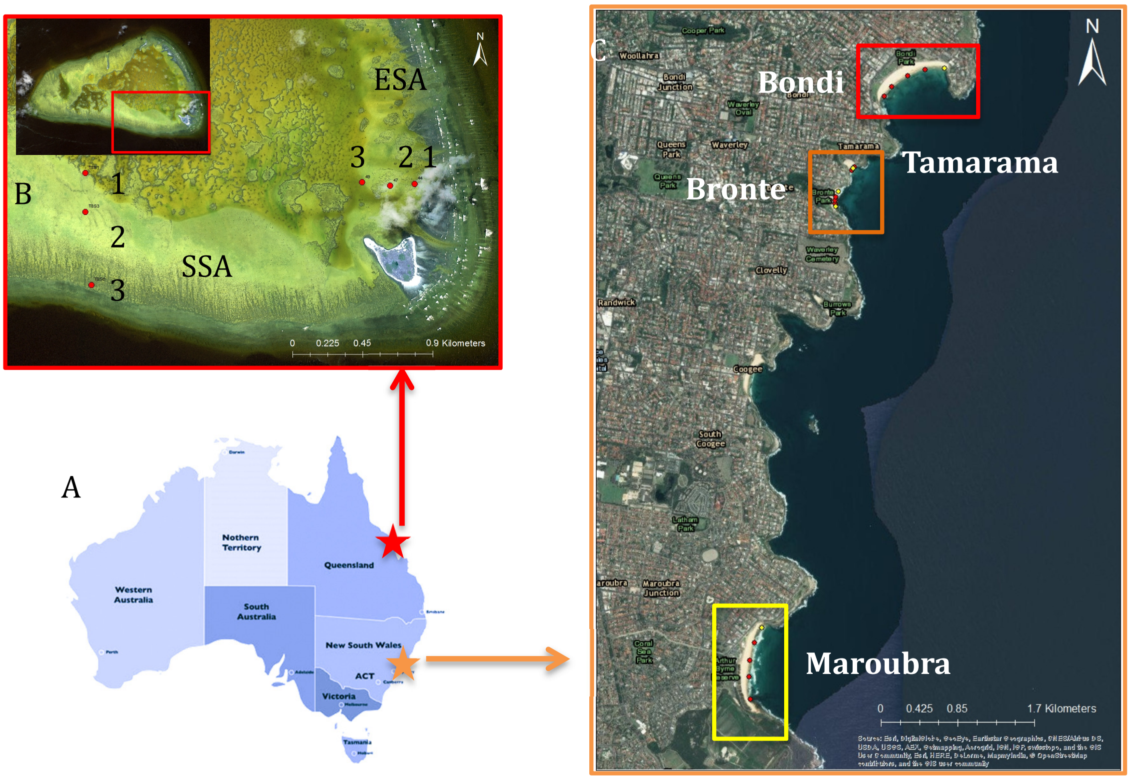


Figure 1. A: Locations of study areas in relation to Australia; B: OTR and locations of six samples on OTR; C: Locations of 4 beaches and 18 samples on eastern Sydney

Methods

Samples preparation

A total of 42 samples were analysed for this study. Among them, 24 surficial samples were collected from study areas and 18 samples were produced in the laboratory. Six samples were collected from two transects on two subtidal sand aprons, southern sand apron (SSA) and eastern sand apron (ESA), on OTR (Figure 1B), which represent PC sediment. Samples from these aprons consist of coral fragments, large benthic foraminifera, molluscs and *Halimeda* remnants (Ford and Kench, 2012) (Figure 2A). The other18 samples were collected from the intertidal area of 4 beaches (3 samples on Tamarama Beach and 5 on each of the other beaches) (Figure 1C) representing MS. Sediments on these beaches are formed by siliciclastic particles and a variable percentage of carbonates due to the presence of shell fragments (Figure 2B). Subsamples of the 18 dried MS samples were treated with hydrochloric acid (HCl) to dissolve all carbonate content. This process led to obtaining 18 PS samples (Figure 2C) and to calculating the percentage of carbonate of these samples.

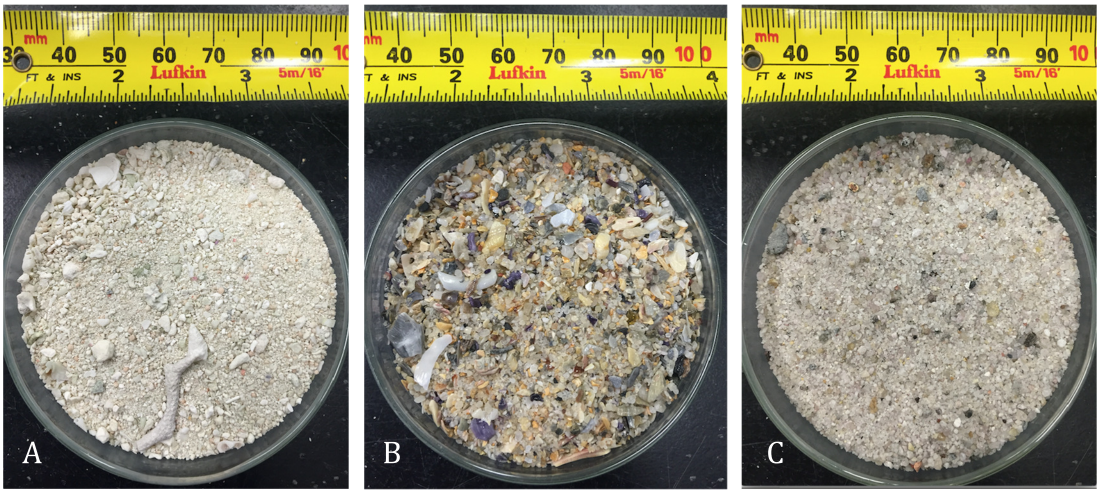


Figure 2. Pictures of PC, MS, PS samples
(A: PC_SSA_2; B: MS_Bronte5; C: PS_Bronte5)

Laboratory analyses

Figure 3 simply but clearly illustrates the processes of the experiment plan. Bulk density was calculated by the mass of sediment in a known volume. Measured fall velocity from settling tube was then converted into mean grain size using the Gibbs et al. (1971) formula and the rapid sediment analyser software (SedRep) (de Lange et al., 1997). Both measured bulk density mentioned above and a literature standard density of 1.85 g/cm^3 (Maiklem, 1968) were used in the grain size calculations from the falling velocity for a measured result and a literature result. Median grain size of sieved sediment of 0-1.4 mm was also measured by LPA.

Subsets of 5 PS and 5 MS samples from 4 beaches were selected to represent a wide variety of sizes and carbonate percentage due to the similar result from each beach, resulting in 16 samples representing 3 groups (PC, PS and MS), which were prepared for further MG3 measurements and analyses.

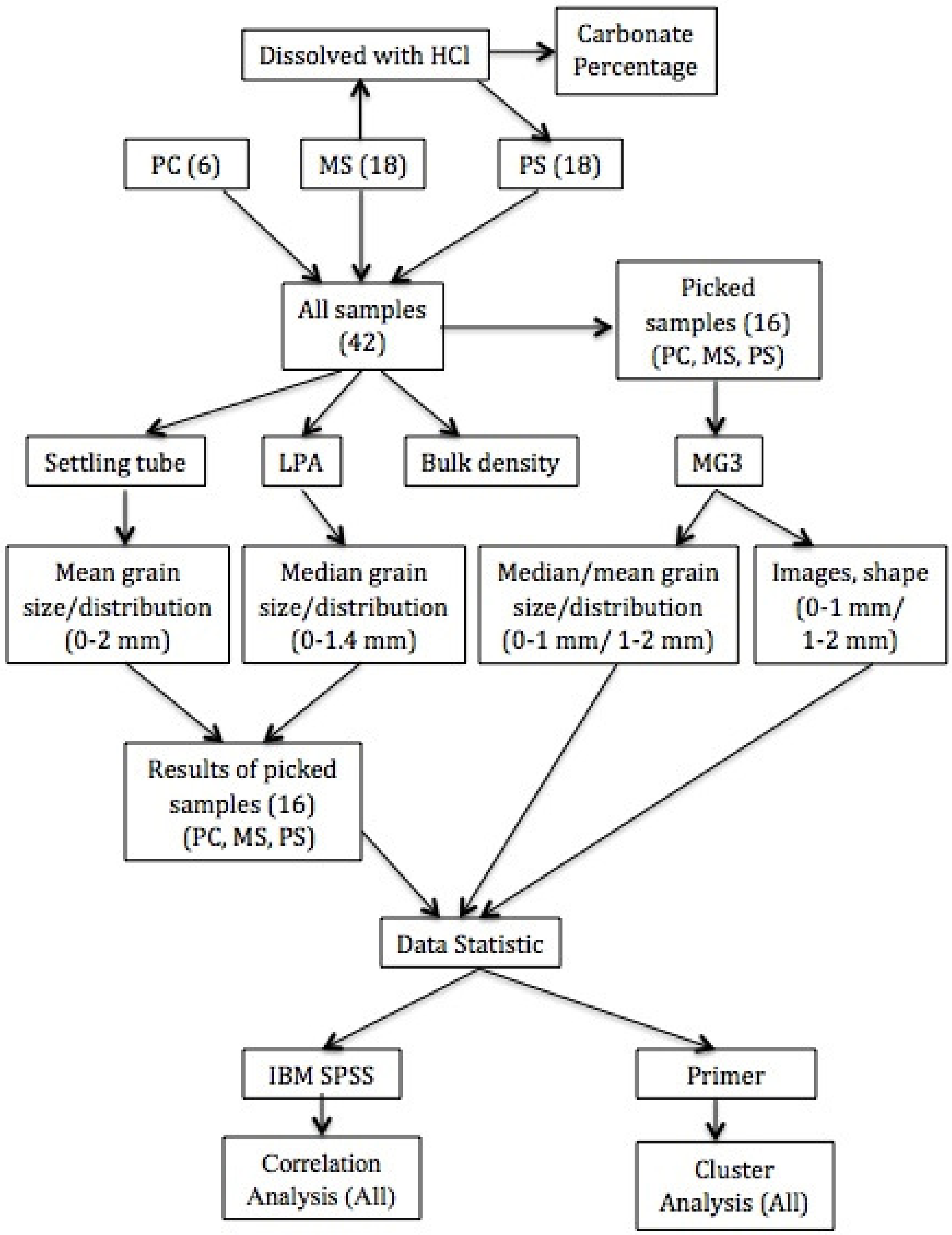


Figure 3. Experiment flow chart

MG3 scanned and stored the images of every particle for further calculation and analyses. Finer sediments (0-1 mm) were sieved and selected in this measurement from each sample due to the 1 mm limitation of Samples Dispersion Unit (SDU) equipment of MG3. Particles were dispersed using SDU automatically, which guaranteed an even arrangement of sands on the plate and reduced the influence of adhesion of individual particles with each other (Polakowski et al., 2014). According to the Morphologi G3 User Manual (Malvern Instruments Ltd, 2008), Parameters (Listed in Table 1) were either captured by the images or by the calculations.

Table 1. Parameters and definitions from MG3 (Malvern Instruments Ltd, 2008)

Parameters	Definition
Area	Visual particle area.
Perimeter	Total length of the particle boundary.
Circle Equivalent (CE) Diameter	The diameter of a circle with the same area as the particle area.
High Sensitivity (HS) Circularity	The ratio of the particle's area to the square of the perimeter of the particle.
Aspect Ratio	The ratio of the width to the length of the particle.
Convexity	The perimeter of the convex hull of the particle divided by the perimeter of the particle. The convex hull can be seen as the border created by an imaginary rubber band wrapped around the particle.
Solidity	The particle area divided by the area enclosed by the convex hull.

Data statistic analyses

A Spearman's correlation analysis was tested using IBM SPSS to determine the statistical significance of the association between any two parameters of size, shape and density. Moreover, cluster analysis was applied on the six different mean grain sizes and median grain sizes of each sand group using Primer to estimate the similarity of the various grain size parameters.

Results

Median grain size and mean grain size

Relationship between median grain sizes of sediment from 0 to 1.4 mm measured by LPA and MG3 are shown in Figure 4. MS samples had a strong and positive relationship. Moreover, regression lines of MS and PS were closely similar with each other and matching with 1:1 relationship line. However, results for PC samples from these two methods were not similar: median grain size measured by MG3 was typically smaller than that by LPA, which was probably caused by the relatively large content of very fine sands in the small amount of samples (fewer than 60 mm^3) used in MG3 measurement.

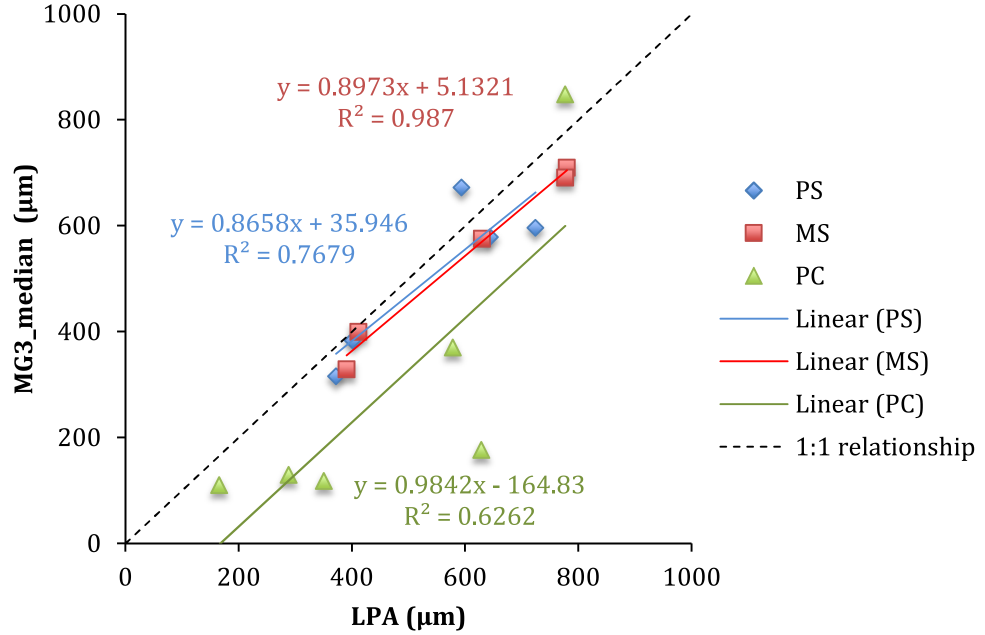
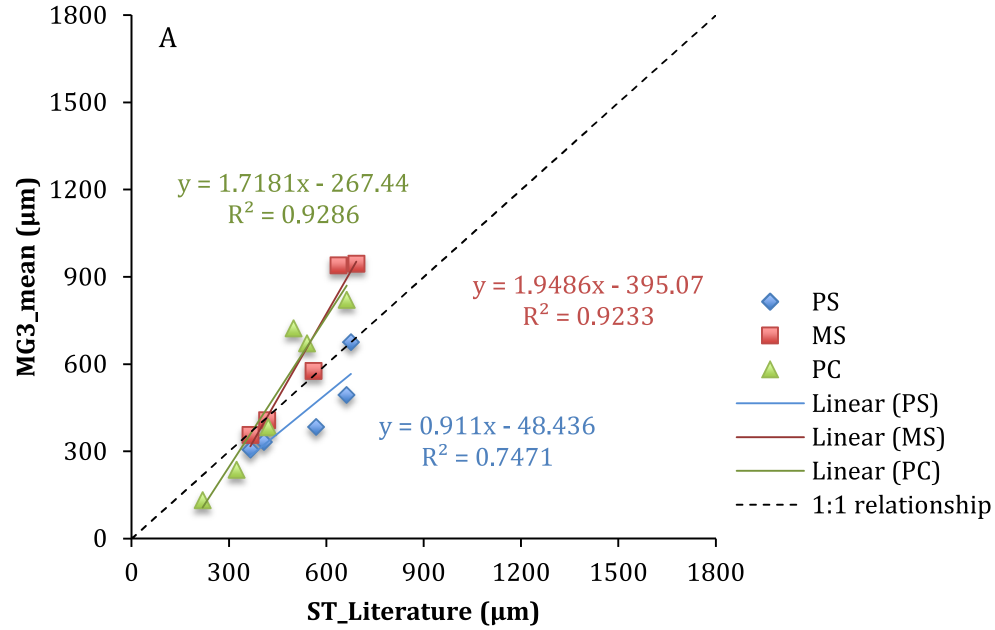


Figure 4. Relationship of median grain size measured by LPA and MG3

The relationships between mean grain sizes of sediment from 0 to 2 mm measured by settling tube and MG3 were different depending on the bulk density used in the calculations. When literature bulk density was applied in the calculations (Figure 5A), positive and significant regression relationship of MS and PC sample were similar. Although, linear relationship of PS sediment was weaker, it was the better fitted one with the 1:1 relationship line. When measured bulk density was used in the calculation (Figure 5B), still relationships of MS and PC were relatively significant. Both PS and MS samples were similar to the 1:1 relationship line. Results for PC samples from the settling tube were typically higher than that from MG3 due to the low measured bulk density. The weight measured by settling tube reflected the real mass of particle, however, the estimated bulk density used in the calculation was lower than the real density of particle. Thus, the grain size of particle would be overestimated.



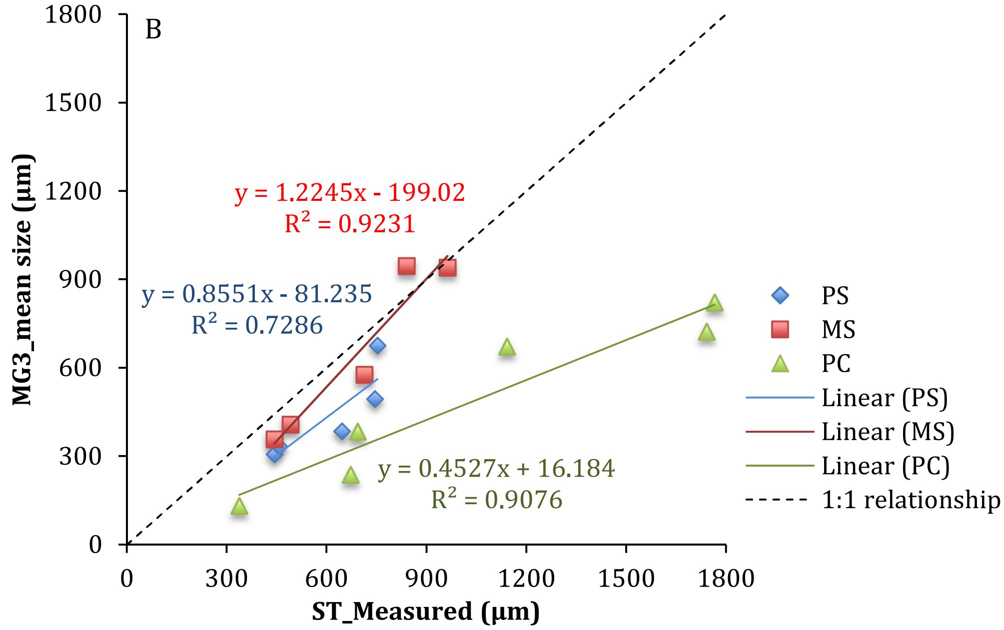
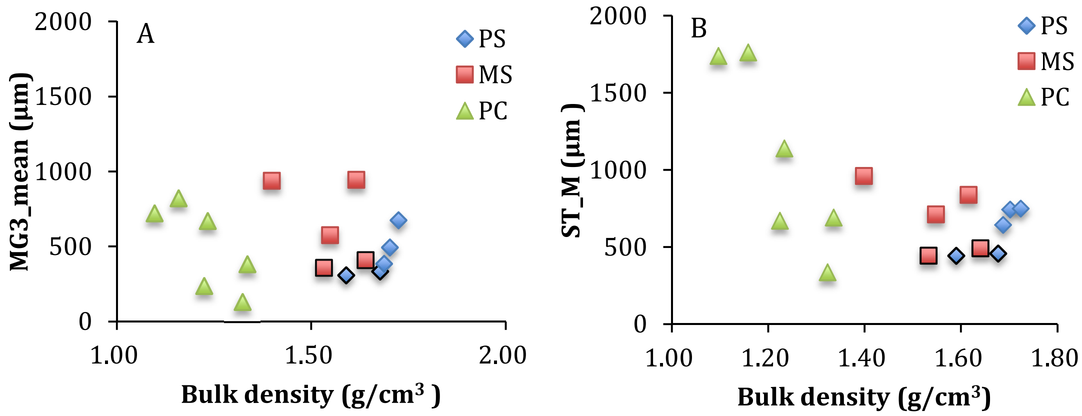


Figure 5. Relationship of mean grain size measured by Settling tube and MG3 (A: Literature bulk density; B: Measured bulk density)

Relationships between bulk density and grain size

Comparing the relationship between bulk density and grain size in the three sediment groups (Figure 6), density of PC samples typically was the lowest and led to the decrease of grain size with its increase. The irregular shape (and probable voids) possibly caused the low density and mostly happened in larger particles. On the contrary, PS samples were roughly divided from MS sediments with slightly higher density and smaller grain size due to their relatively regular shape. MS and PS samples from Bondi Beach and Maroubra beach (highlighted in black edge) were not separated as well as the others because of their low carbonate content. Comparing between MG3 and settling tube (Figure 6A, B), density influenced more on mean grain size of PC measured by settling tube, due to measurements taking into account the hydrodynamic behavior of the particles.



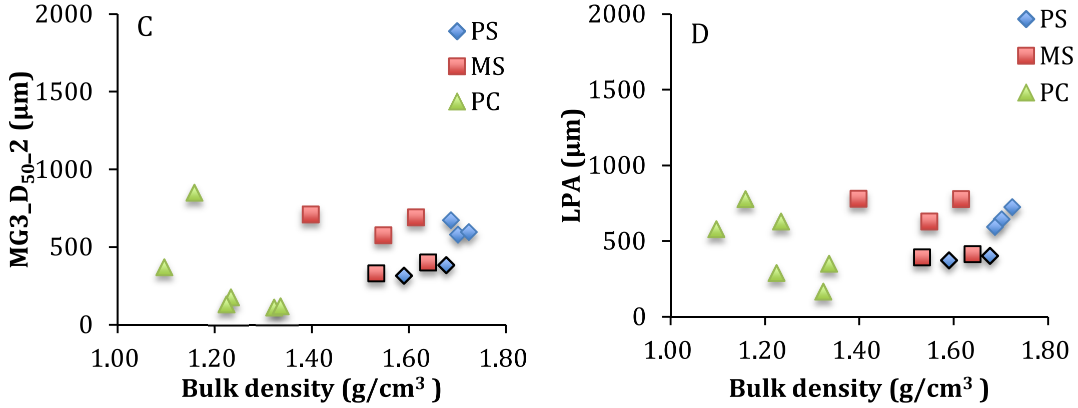
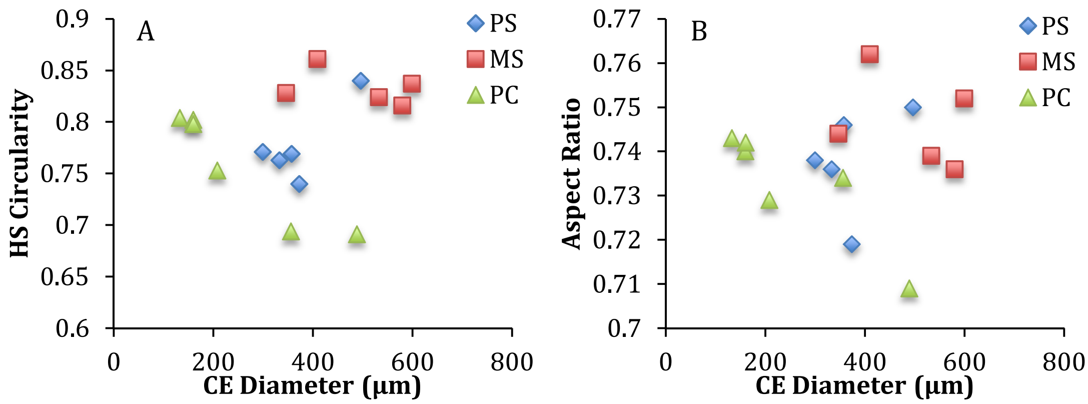


Figure 6. Relationship between bulk density and grain size parameters (MS and PS samples from Bondi and Maroubra Beach were highlighted in black edge)

Relationships between CE Diameter and shape parameters

Sediments (Figure 7) had distinct division between PC and beach samples with lower shape parameters and smaller CE Diameter, because of the irregular shape of PC samples and some very fine component. On the other hand, MS samples were divided from PS sediment by relatively higher values, which was probably because the fine flat shell fragments in MS samples were eroded into round and smooth shape. Division in Figure 7B was worse defined compared with the other graphs illustrating that aspect ratio was less influenced by sediment type. Results of solidity and convexity of all sediments (Figure 7C, D) had higher value than HS circularity and aspect ratio (Figure 7A, B). Particles had relatively smooth surface but elongate shape was possibly the main reason.



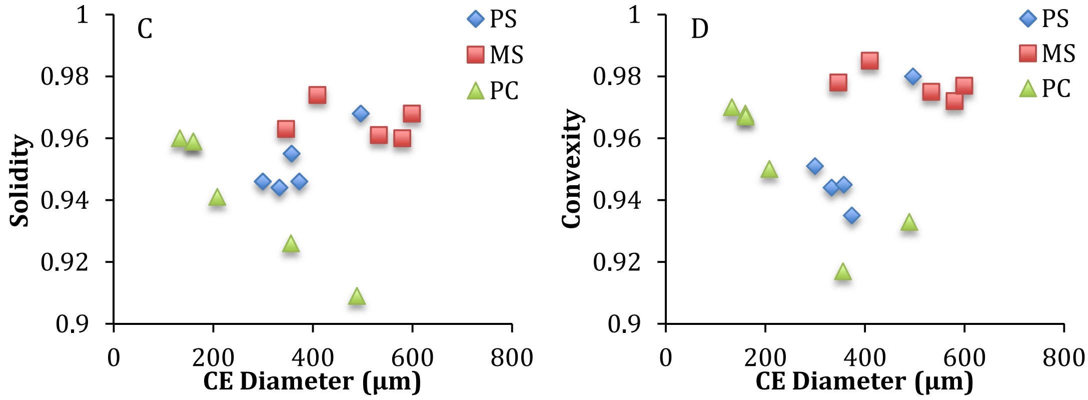
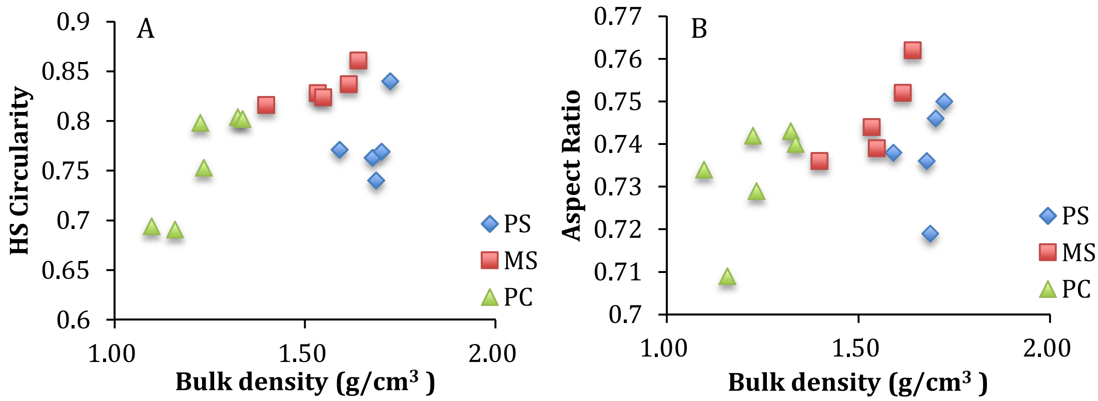


Figure 7. Relationship between CE Diameter and shape parameters

Relationships between bulk density and shape parameters

It was distinct that PC samples had lower bulk density and shape parameters (Figure 8). Those PC samples with low bulk density mostly contained large amounts of irregular coarse particles; therefore, they had lower shape parameters. MS samples had middle bulk density but the highest shape parameters. The shell fragments in MS samples probably reduced the bulk density due to their lower density, however, the erosion and abrasion made the smooth and flat shell better circle in shape. The uniform shape and fine grain size led to the highest density of PS samples. However, the reaction with acid during the production probably resulted in the relatively irregular shape of particles. Moreover, compared with beach samples, PC sediment corresponded to a broader range of density and shape parameters, because of its high variety.



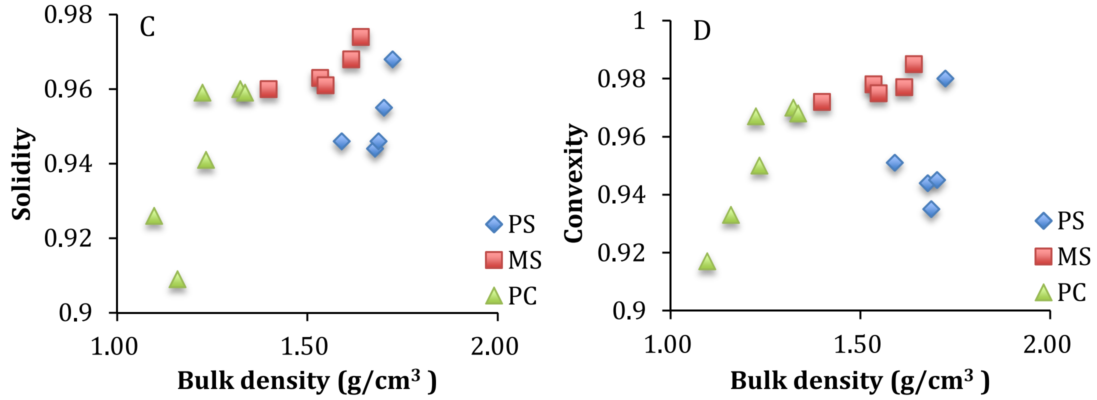


Figure 8. Relationship between bulk density and shape parameters

Mean and median grain size statistic analyses

Spearman's correlation statistic among size, shape and density

Depending on the Spearman's correlation test (Table 2), significant relationships between mean or median grain size and shape parameters were obvious for PC samples due to the influence of the irregular shape. However, for MS samples, the relationship between density and shape was found to be significant, while both of them had non-significant correlation with size. One possible reason was that beach samples had relatively similar character of density and shape. Different sizes were probably caused by the exterior factors, such as various wave conditions, which had less relationship with the inside characters.

Table 2. Spearman's correlation among size, shape and density (HS: HS Circularity; AR: Aspect Ratio)

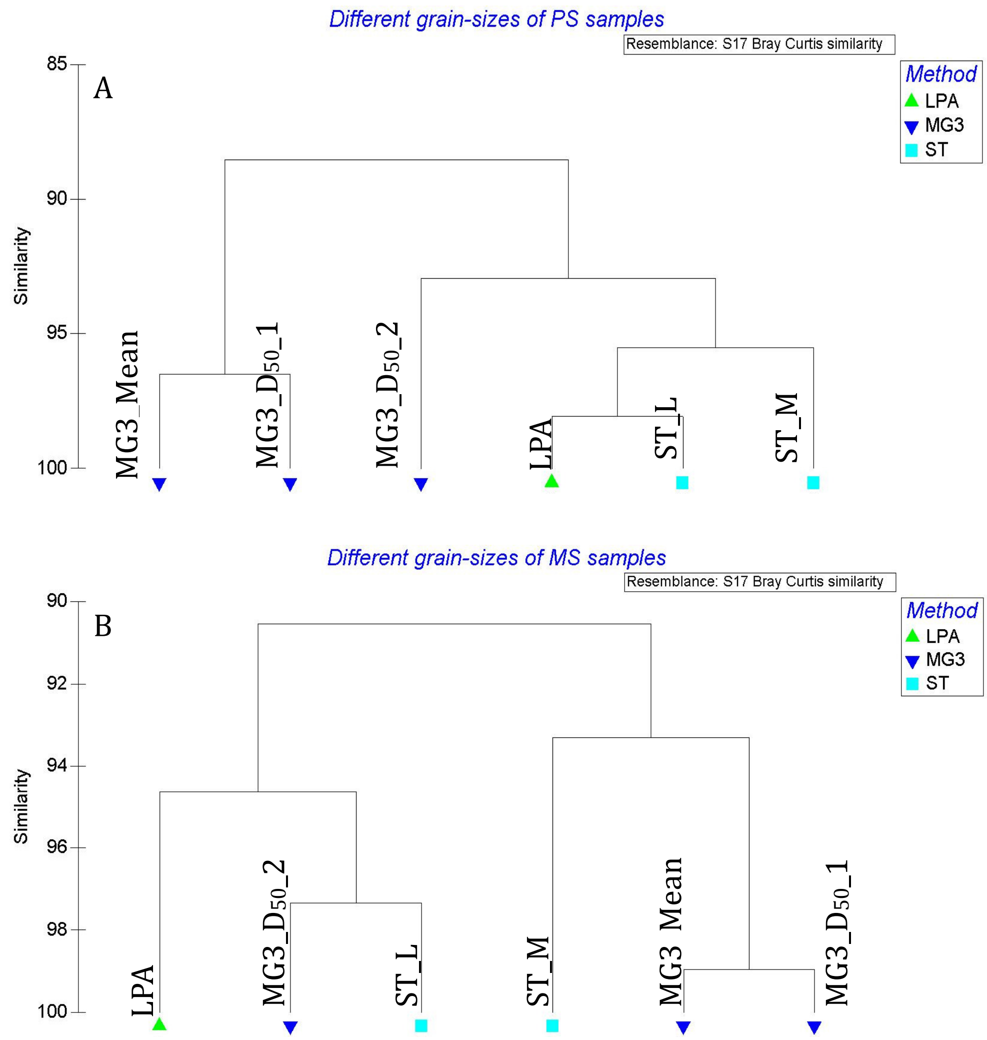
	Size/Density	HS	AR	Solidity	Convexity	Density
PC	MG3	-1.000**	-0.886*	-0.986**	-0.943**	-0.829*
	ST	-0.943**	-0.943**	-0.986**	-0.886*	-0.657
	LPA	0.886*	-1.000**	-.928**	-0.771	-0.486
	Density	0.829*	0.486	0.754	0.886*	1.000
MS	MG3	-0.200	-0.200	-0.200	-0.600	0.000
	ST	-0.500	-0.500	-0.500	-0.800	-0.300
	LPA	-0.500	-0.500	-0.500	-0.800	-0.300
	Density	0.900*	0.900*	0.900*	0.700	1.000
PS	MG3	0.100	0.300	0.667	0.100	0.900*
	ST	0.205	0.462	0.763	0.205	0.975**
	LPA	0.300	0.600	0.821	0.300	1.000**
	Density	0.300	0.600	0.821	0.300	1.000

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Cluster analysis of grain size parameters

Six mean and median grain sizes obtained by various methods were compared objectively by cluster analysis to show how similar of these grain sizes in each type of sediments. Statistic test provided the results that PC samples showed significant lower similarity (~60%), while PS and MS samples owned high values, approximate 88% and 90% respectively (Figure 9). It was illustrated that obvious distinction occurred among the six mean or median grain size results of PC samples, which was impacted by the irregular shape and low bulk density. On the other hand, the relatively uniform shape and density led to the high similarity between grain sizes of PS and MS sediments.



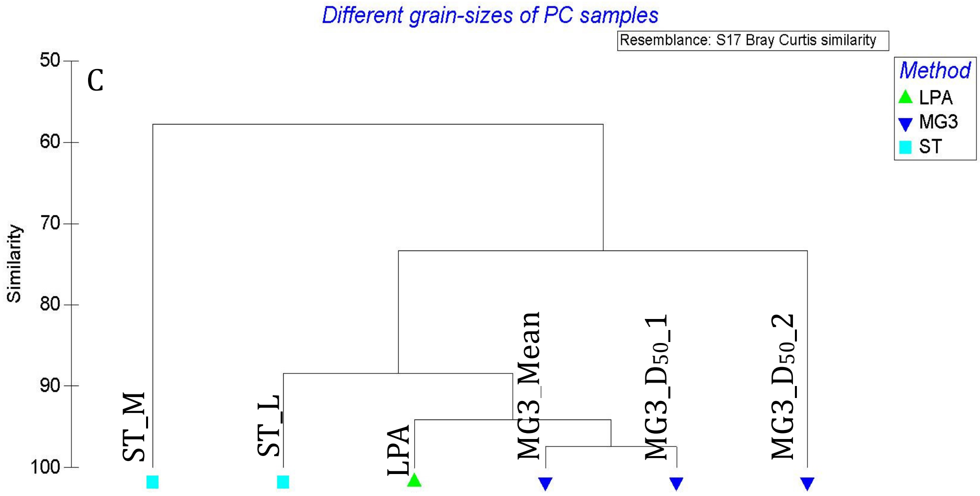


Figure 9. Cluster analyses of different grain size results (A: PS samples; B: MS samples; C: PC samples)

Discussion

Comparison among PS, MS and PC samples

Mean grain size and median grain size

Depending on the relationship of mean grain size or median grain size between different methods (Figure 4 and Figure 5B), PS and MS samples typically show high coincidence with 1:1 relationship line, while PC samples measured by MG3 usually have smaller grain size results, which illustrate that PS and MS samples possess small difference of mean grain size and median grain size in various method and PC produces significant variation. Although, a paucity of research has compared the grain size result between MG3 and other methods, numerous researchers have studied the differences of mean grain size result of PS or PC sediments between dry-sieving and settling tube (Kench and McLean, 1997, Komar and Cui, 1984, Paphitis et al., 2002, de Lange et al., 1997) and median grain size result between dry-sieving and laser diffraction method (Blott and Pye, 2006, Rodríguez and Uriarte, 2009), giving the conclusions that PS sediment has small differences in size estimates while PC samples possess large variation. Results in this study are in agreement with previous findings.

Matthews (1991) proposed that particle size results from various methods are related to the sediment physical properties and the theory of the method involved. As mentioned before, grain size of PC sample measured by MG3 is possibly underestimated due to the very fine sand fraction. As can be seen in Figure 2A, PC sample contains particles with heterogeneous grain size and shape. Therefore, it is difficult to include and represent all kinds of particles in the small amount of sample (fewer than 60 mm^3) used in one scan. In this case, very fine sand possibly occupies relatively larger fraction, leading to the underestimation of mean and median grain size. Although MS samples also show relatively high extent of difference (Figure 2B), it is mainly the mixture of fine siliciclastic sediment and coarse shell fragments, which is short of the very fine component, reducing the influence of multiformity. Moreover, overestimation of the mean grain size of PC samples measured by settling tube is the second reason of the difference between various techniques. Irregular shape of PC sediment increases the pore when measuring the bulk density, which decreases the results. Whereas, in reality, the denser particles deposit faster and produce larger estimated size when using the underestimated bulk density (Kench and McLean, 1997). Concerning LPA, although this technique has high precision for a range of particles (Blott et al., 2004), it is short of the reaction of hydrodynamic characteristic of sediments. Accordingly, it is inappropriate to represent PC sediment by any individual mean grain size or median grain size.

Similarity statistic of different grain size results

Cluster analysis of PS and MS samples shows extremely high similarity of six different mean or median grain sizes investigated by three techniques (Figure 9A, B), however, much lower results for PC sediments (Figure 9C). The statistic result corresponds to the comparison and discussion about the relationship between various size results mentioned above. The distinction between various grain size parameters for PC samples is caused by the overestimate and underestimate of the measured grain sizes. Consequently, it is inappropriate to make these grain sizes as the representation of PC sediments. The high similarity between various grain sizes for PS and MS samples illustrates that these grain size parameters are close to the real grain size value; therefore, they are available to represent the particle size of PS and MS samples.

Influencing factors on the measurement of particle size

Results of Spearman's correlations (Table 2) indicate the significant and insignificant relationships among size, shape and density in three types of samples. Combining the relationship with measurement results, it is indicated that shape and density play an important role on the estimate of mean and median grain size by various methods, which has been proved by numerous previous researches (Gibbs et al., 1971, Kench and McLean, 1997, Maiklem, 1968, Pye and Blott, 2004, Smith and Cheung, 2002, Blott and Pye, 2001).

Density

Density typically has more influence on the mean grain size from settling tube (Figure 6) because of the hydrodynamic measurement process. As mentioned before, when particle density is higher than the bulk density, particle will settle faster and result in a larger grain size; on the contrary, if particle density is lower than the bulk density, grain size result will be underestimated (Kench and McLean, 1997). For example, comparing the relationship of mean grain size between literature bulk density and measured bulk density (Figure 5), significant difference can be observed in PC samples, followed by MS samples; however, PS samples are barely influenced. Therefore, the selection and application of density directly influence on the measurement of mean grain size, especially for PC sediment. Literature density is not appropriate for all the samples due to the various component and location. However, it is complicated to use the particle density because of the difficulty to measure the mass and volume for each small grain, especially for the very fine particles. Accordingly, bulk density is still the most common used value (Kench and McLean, 1997, Maiklem, 1968) although it has variations due to the pore volume (Blake, 1965).

Shape

According to the results (Figure 7), PC samples have relatively low values of shape parameters, indicating its irregular shape, which results in the large variation of grain size measured by different techniques. Blott and Pye (2001) proved that various sizes are impacted by grain shape and other properties to a greater or lesser extent. In this study, PC samples correspond to broader range of shape parameter values and had approximately negative relationships with CE Diameter (Figure 7), illustrating that with the increase of particle size, grains become more irregular. Beach samples have relatively high values of shape parameters and do not show obvious tendency between shape and size, indicating the negligible influence on PS and MS samples, which corresponded to the insignificant relationship from the Spearman's correlation statistic (Table 2). The erosion and abrasion of waves make a difference on the shape and grain size of beach sediments, therefore, the influence from relatively uniform shape on the grain size of beach particles is not as obvious as PC samples.

Comparison between density and shape

There are relatively significant relationships between bulk density and some shape parameters for finer fraction of PC and MS samples (Figure 8, Table 2). It is not difficult to understand the influence on bulk density from shape as irregular shape reduces the bulk density due to the possibly increasing void. However, it is challenging to decide which factor plays a more important role on the measurement of grain size due to the various investigation methods and relationships between these two factors. On one hand, shape probably influences more on mean and median grain size measured by MG3 and LPA since the sizes are calculated depending on the estimated area and volume, respectively. On the other hand, impact from bulk density cannot be ignored when using settling technique. However, as mentioned before, the irregular shape of particles results in the underestimation of bulk density and decreases the fall velocity due to the oscillated pathway and additional surface drag (Maiklem, 1968, Paphitis et al., 2002). Consequently, it is assumed that shape has a broader influence on the measurement of grain size.

Combination of shape and density

A particle scale investigation was done by Smith and Cheung (2002), giving the conception of median nominal and equivalent diameters and providing a helpful understanding of the characteristic size parameter of calcareous sand. Nevertheless, the procedures to calculate this median diameter require the details of each particle, such as length and weight, which is time consuming.

Solidity density

A new combined density is proposed here to solve or reduce the problem that grain size results from various techniques are not consistent and cannot appropriately represent PC sediments. So far, settling tube analysis is the most recommended and common method to measure grain size distribution and mean grain size taking into account the hydrodynamic process and encompassing the influences of different characters of particles, including size, shape and density (Smith and Cheung, 2002). Accordingly, for this new parameter, mean grain size is still measured by settling tube. However, as discussed above, the bulk density used in the calculation leads to the overestimation of grain size because of the void between particles, which could be better reflected by solidity. And at least for PC samples, there is a significant relationship between grain size and shape parameters (Table 2). Consequently, a new solidity density is proposed here to decrease this overestimate. Depending on the definition of solidity from MG3 user manual (2008), solidity is the particle area divided by the area enclosed by the convex hull (Figure 10, Equation 1), which can be considered as the border around the particle.

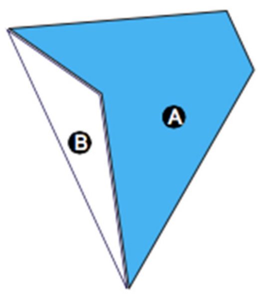


Figure 10. A: Area of particle; B: Space between particle and border

$$Solidity = \frac{Area\ of\ A}{Area\ of\ A+B} \qquad \text{Equation (1)}$$

Moreover, when calculating the bulk density, pore volume is considered as the particle volume due to the irregular shape of grains, which is similar with the space B in Figure 10. Therefore, solidity density is defined as below (Equation 2) to reduce the influence of interspace between particles to better represent the real density of sediment. The unit of solidity density (g/cm^3) is same with density because of the dimensionless of solidity.

$$Solidity\ \ density = \frac{Bulk\ \ density}{Solidity} \qquad \text{Equation (2)}$$

Relationship of mean grain sizes converted based on the solidity density is shown below (Figure 11) and compared with the results analysed before (Figure 5B). As can be seen in the graph, slight influence occurs on PS and MS samples. Although for PC sediment, there is still difference with 1:1 relationship line, significant improvement can be observed depending on the new density.

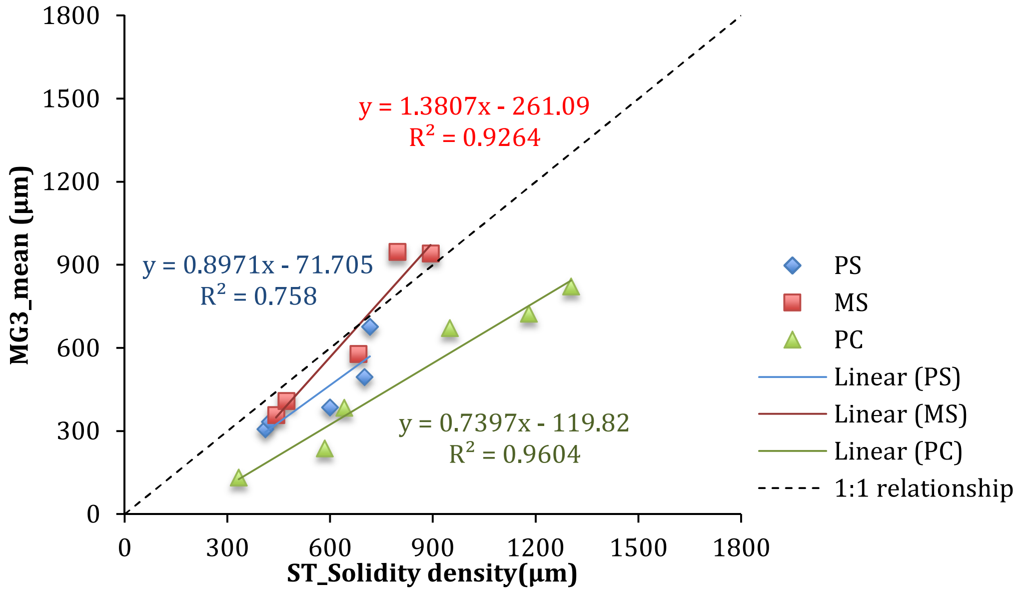


Figure 11. Relationship of mean grain size measured by settling tube (Solidity density) and MG3

Application range

According to the discussion and comparison above, PS and MS samples are not impacted obviously by solidity density, which is possibly because the carbonate sediments in MS and PC samples are various materials and have different characters. Therefore, it is initially proposed that solidity density is available on all these three types of sediment, regardless the percentage of carbonate in samples. Nevertheless, considering the negligible influence, the application of the solidity density on PS and MS samples is probably an over complication because these sediments can be adequately represented by the bulk density results. Therefore, it is concluded that the application of solidity density is a useful solution for PC sediments but not necessary for PS and MS samples.

Further research

This study was undertaken during one university term only, therefore further research is required for better demonstration and understanding of some conclusions. Firstly, MS samples combined with siliciclastic sand and coral fragments based on a series carbonate percentage should be prepared and measured to compare with PS and PC sediment. Different materials and characters lead to the incomparability between MS and PC samples, which influence some of the conclusions, for instance, the relationship between the impact of solidity density and carbonate percentage in the samples. Moreover, particle density is still essential to this study. On one hand, the comparison between the application of particle density and solidity density can indicate the representation extent of solidity density. On the other hand, the impact of particle density on the measurement of grain size can be analysed and compared with influence from shape. Lastly, the mean grain size calculated with solidity density should be investigated on the application of sediment transport. Moreover, the differences between PC and PS samples about sediment transport processes need to be studied as well for better understanding and combination of the whole beach morphodynamics.

Conclusions

This study compares and analyses the representation of different mean grain sizes and median grain sizes of siliciclastic, carbonate and mixed sediments measured by various techniques, including settling tube, laser particle and Malvern Morphologi G3 analyses. It is concluded that different grain size parameters can represent siliciclastic and mixed samples due to their high similarity; however, there is no good enough representation for carbonate sediments due to the irregular shape and density of the sediment particles. Moreover, shape probably plays a more significant role than bulk density on the measurement of grain size parameters. To figure out a representation for PC samples, solidity density is defined as the ration between bulk density and solidity and when used to calculate grain size from settling tube measurements provides better results for the pure carbonate (coral) sediment samples.

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