TUMBLING EXPERIMENT FOR THE ESTIMATION OF ABRASION AND MASS LOSS OF COASTAL SEDIMENTS FROM AN ARTIFICIAL COARSE-CLASTIC BEACH

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INTRODUCTION

In order to assess the accretive or erosive pattern of a stretch of coast, it is essential to estimate its sediment budget, i.e. the quantification of all sources and sinks of sediments. The sediment budget is the basis of a reliable coastal management plan (Ruol et al., 2018). In fact, coastal erosion is usually the result of a negative balance of factors, both natural and anthropogenic, that operate on different scales, none of which may be considered the single cause.

Recently, a massive abrasion rate of coarse-clastic sediments was documented in artificial nourished beaches. The mechanism is associated with both mild wave conditions and extreme stormy events, which could also induce chippings. This phenomenon could decrease the durability of nourishments (Bertoni et al., 2012 and 2016) and is usually not considered in the sediment balance.

Abrasion was largely investigated along rivers (Lewin and Brewer, 2002), however, the prediction of this phenomenon along beaches is still little studied.

The mass loss due to abrasion can lead to errors in the analysis of erosive and accretive patterns after the nourishment and consequently to erroneous coastal management strategies. Moreover, the sediment grain size in a given beach (naturally present or selected for nourishments) is strictly related to the typical wave energy. The abrasion mechanism and the possible pebble chipping change the sediment grain size, which could become unstable and not adequate for the local wave climate.

Based on the large cost of nourishments, which also require strong monitoring in the subsequent years, it is crucial to understand the abrasion and mass loss rates of the filling sediments to extend the life of artificial beaches as long as possible.

MATERIALS AND METHODS

The actual investigation includes laboratory analyses on sediments collected on a coarse-clastic nourished beach, which will be compared with an in-situ analysis.

For the present study, pebbles from Barbarossa Beach, Pisa, Italy (Fig. 1) were collected. The investigated area is an artificial beach that was built to counteract the erosion processes affecting this stretch of coast. During the last 80 years, a serious erosive trend affected this sector of the Tuscany coast, whose main reasons have to be ascribed to the decrease of the major sediment source, the River Arno sediment supply. To manage this coastal erosive trend, the local authorities created a series of artificial pebble beaches using waste from marble quarries.

Two sets of pebbles (named A and B), formed by 7 stones with both rounded and angular shapes, were selected. Their weights range between 957 g and 1938 g (Table 1).

Figure 1 - Aerial view of Barbarossa Beach, Pisa, IT

To allow the unambiguous identification of each pebble before and after the experiment, a Low Frequency RFID technology was exploited (Bertoni et al., 2010, Benelli et al., 2012). RFID is basically a radio system composed of two different kinds of devices, the reader and the transponders ("tags"). The reader is the device used to perform the actual identification operation: it generates an electromagnetic field that can operate at different frequencies, that is used to interrogate the tags. The tags are the smart devices coupled to the item to be identified and, in their simplest version, they can be fully passive, i.e. without a battery. In the present investigation, the unique hexadecimal code stored in the memory of the transponder, inserted inside each pebble, was read by means of a 125 kHz RFID reader, allowing the univocal recognition.

Table 1- Weight of the tested pebbles divided in the two sets

set A		set B	
pebble	weight (g)	pebble	weight (g)
n0	1649	n0	1007
n1	1439	n1	1084
n2	1938	n2	1668
b0	1064	b0	1091
b1	1518	b1	1491
b2	1051	b2	957
g0	1590	g0	1777

In order to investigate the progressive abrasion and the mass loss, the pebbles were inserted into a tumbling Los Angeles (L.A.) machine to measure the abrasion resistance. The L.A. machine consists of a steel rotating drum (diameter of 70 cm), mounted on a base frame

(Figure 2). The cylinder rotates at a speed of 31 - 33 rpm and the machine is fitted with an automatic digital counter which can be pre-set to the required number of revolutions of the drum. During each revolution, the pebbles degrade by abrasion and impact with other elements. At the end of each series of revolutions, the single pebbles are identified by reading the embedded RFID transponder and the percentage loss is measured. Set A was tested up to 500 revolutions, whereas set B was tested up to 5000 revolutions. During the test on set A, the grain size of the resulting abraded "powder" was quantified every 20 and 50 revolutions.

Figure 2 - Los Angeles machine

RESULTS

The results acquired from the tumbler provide an interesting dataset about the progressive trend of abrasion and mass loss measured on individual pebbles. These data document how fast a specific lithology (marble) would wear.

During the test on set A, two pebbles broke and three pebbles lost slivers with dimensions of about 100-200 gr. During the test on set B, three pebbles broke and two (n1 and n2) were completely abraded after 2000 revolutions. Figures 3 and 4 show set B before the tumbling experiments and after 500, 2000 and 5000 revolutions.

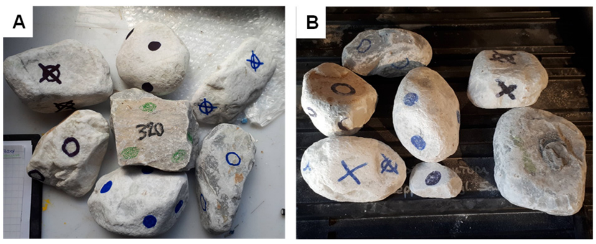

Figure 3 - Pebbles of set B: a) before the tumbling experiment; b) after 500 revolutions

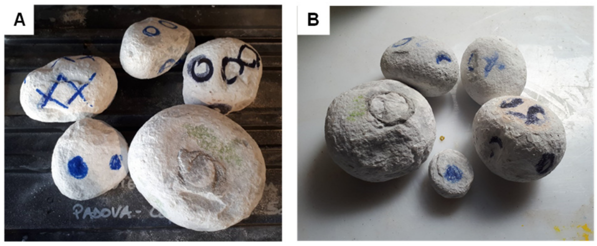

Figure 4 - Pebbles of set B: a) after 2000 revolutions; b) Pebbles after 5000 revolutions

The rate of variations of the pebbles weight, evaluated as the weight after each series of revolutions divided by the initial weight, is shown in Figure 5. The sudden steps are associated with broken pebbles and the loss of slivers. Considering only the non-broken pebbles, the average weight variation after 5000 revolutions is approximately 40%.

Figure 6 shows the weight loss per revolution. During the first 500 revolutions the average loss is approximately 0.5 g/revolution, whereas, during the revolutions between 500 and 5000, the average loss is approximately 0.15 g/revolution. This is probably due to the strong decrease of the pebbles dimensions and the roundness achieved. These results confirm that the abrasion mechanism largely changes the sediment grain size, which could become unstable and not adequate for the local wave climate.

As far as the "powder" produced by the abrasion, the mean grain size d_{50} of this resulting material, quantified during the test on set A, was equal to d_{50} = 0.3225 mm after 20 revolutions and equal to d_{50} = 0.2561 mm after 50 revolutions.

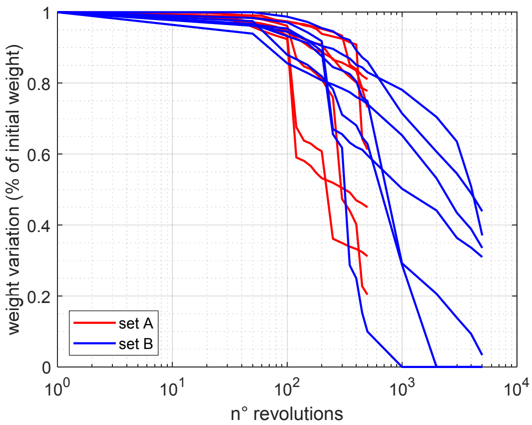

Figure 5 - Weight variation (ratio between the final weight and the initial weight) of the pebbles for the two tested sets

To check if the results are somehow relatable to the actual abrasion mechanism, the percentage of variations evaluated with the L.A. machine was compared with the impressive abrasion measured by Bertoni et al. (2016) during an in-situ campaign. A set of "tagged" pebbles was released before the winter season (November 14th, 2013) on the same beach considered for the present study. Four recovery campaigns were carried out after 3, 8, 10 and 13 months. The authors found that after 13

months the rate of variation was of the order of 40% essentially caused by the collisions due to wave motion under high-energy and low-energy conditions.
Wave measurements were available during the in-situ campaign from the Gorgona wave buoy, 20 miles offshore the Barbarossa beach. During the first 3 months (Nov – Feb) 10 stormy events occurred, characterized by maximum significant wave height (*Hs*) higher than 2 m and the *Hs* 99th percentile for the whole period was 3.16 m. Between the 3rd and 8th months (Feb – Jul), only 3 storms with Hs > 2m occurred and the *Hs* 99th percentile was 1.95 m. Between the 8th and the 10th months (Jul – Sep), no high storms occurred and the *Hs* 99th percentile was 1.17 m, finally between the 10th and the 13th months (Sep – Dec), three storms were measured and the *Hs* 99th percentile was 2.06 m.
Considering the incoming waves of each of the periods, it is possible to calculate the cumulative parameter ΣHs^2 (proportional to the energy of the wave that impacted the coast) as follows: 1722 m^2 after 3 months, 3384 m^2 after 8 months, 3708 m^2 after 10 months and 4627 m^2 after 13 months.

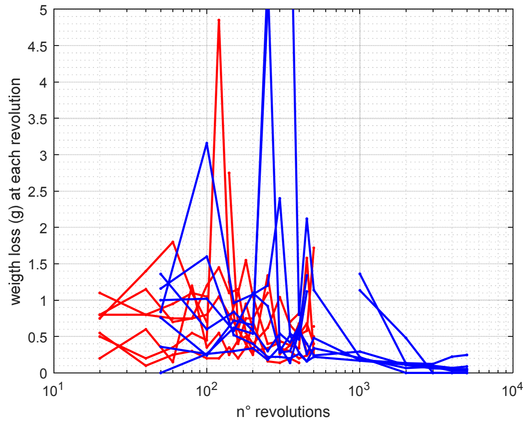

Figure 6 - Pebbles weight loss after each revolution (g/revolution) for the two tested sets

Figure 7 shows the comparison between the results obtained with the L.A. experiment and the field campaign of Bertoni et al. (2016) in terms of weight variations of the pebbles.
The comparison is performed considering an exponential relationship between the cumulative wave energy impacting the coast and the number of revolutions in the tumbling machine. Only the non-broken pebbles were considered and the black line in the figure is the average variation obtained with the laboratory tests. The final equation is $n°rev = 12.71*\exp(0.001286 * \Sigma Hs^2)$.
The comparison shows a slightly good agreement, in particular for the in-situ results after 8, 10 and 13 months.

CONCLUSIONS

The experimental analysis shows that the abrasive mechanism induces a variation of the marble pebbles that reach 60-70% of the initial weight after 1500 revolutions and 40% after 5000 revolutions. This rate is comparable to the one found by Bertoni et al. (2016) after 10 months and 13 months during an in-situ campaign. The comparison between the experimental dataset and the observed abrasion rate considers the actual wave energy that impacted the investigated coast.

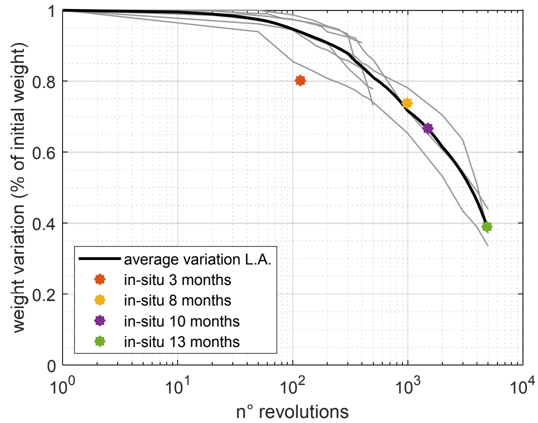

Figure 7 - Comparison between weight variations of the non-broken pebbles tested in the L.A. machine with the one measured by Bertoni et al. (2016)

This preliminary study correlates the rate of abrasion due to the wave action on pebbles to the results of the Los Angeles tests. The experimental dataset will be also compared to that obtained by a new in-situ experiment that will be carried out in fall 2022. Matching the two datasets will provide information on the actual reliability of tumbling experiments replicating the natural environment. The final results may prove the relevance of the abrasion mechanism in the planning stage of nourishment and, more in general, in coastal erosion for coarse and shingle beaches. The findings could also lead to formulating parallelism with gravel and probably even with sandy beaches.
The acquired datasets will be made available for further investigation, to be carried out by means of artificial intelligence algorithms, to implement prediction tools for the automatic modelling of the coastal morphodynamics.

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