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Dynamic Image Analysis of Clasts' Morphological Changes due to Fluvial Abrasion

Tamara Kuzmanić (1) and Matjaž Mikoš (2)

(1) Faculty of Civil and Geodetic Engineering, University of Ljubljana, Ljubljana, Slovenia,
e-mail tamara.kuzmanic@fgg.uni-lj.si

(2) Faculty of Civil and Geodetic Engineering, University of Ljubljana, Ljubljana, Slovenia,
e-mail matjaz.mikos@fgg.uni-lj.si

Abstract

Mass losses that mineral clasts experience after being subjected to a short-term laboratory abrasion process are relatively low but are accompanied by noticeable morphological (particularly textural) changes. Quarried, dolomite aggregate clasts were subjected to several consecutive short-term abrasion cycles (starting from a 10-min cycle). Abrasion cycles were conducted in a micro-Deval apparatus in the presence of water, with the aim to mimic fluvial abrasion. Quarried aggregate material was selected as it was minimally weathered post-exploitation, representing a fresh clast entering fluvial sediment transport after being detached from the bearing rock mass. Before and after each cycle of abrasion, the clasts were weighed and analysed using a dynamic image analyser – Microtrac Camsizer XL and the accompanying PartAn 3D software. The experimental methodology and the methodology for joining data from several repetitions of analysis to a single data set are presented, as well as the joint data analysis. Also, the preliminary results of changes in morphological parameters due to abrasion are presented.

Keywords: Clast morphology; Fluvial abrasion; Dynamic image analysis

1. INTRODUCTION

Recognition of particles' morphological parameters (shape, form, angularity, and texture), along with recognition of the changes those parameters undergo during abrasion processes could be used to identify what mechanism a particle had experienced (Novak-Szabo, 2018). As well as abrasion itself, rounding of a particle greatly depends on the shape of the particle (Wentworth, 1941). For an accurate description of changes a particle undergoes during fluvial abrasion, it is important to describe and quantify morphological parameters and changes in those parameters. Cassel et al. (2021) found that the particles' morphology has a great influence on its' mobility. Along with the particles' mobility comes particles' susceptibility to fluvial abrasion, whether in motion or in-place.

Image analysis (especially dynamic image analysis - DIA) presents a simple and fast method for morphological parameters recognition, compared to the conventional, manual method. Different methods for description of shape and form (morphological) characteristics have been evaluated by numerous authors in diverse fields of use, such as in petroleum engineering for fracturing proppants analysis, in civil engineering for railway ballast degradation analysis, in mineral processing for analysis of products' geometric features, etc. (e.g., Bian et al., 2021; Gawenda et al., 2020; Lyu et al., 2019; etc.), indicating the great potential of the image analysis methods. The image analysis methods can be divided into dynamic or static analysis, depending on whether the analysed material is in motion. Furthermore, image analysis can be divided into 2D or 3D. In the research presented, a quasi-3D dynamic image analysis was used. A series of papers by Li and Iskander (2021a; b) and Li et al. (2021a; b) confirmed the usefulness and applicability of 3D dynamic image analysis for natural sands. We tested the method for natural clasts.

2. EXPRIMENTAL SET UP

Quarried dolomite aggregate clasts (particles), from the size class 50/100 mm, weighing between 150 and 300 g were randomly selected for the experiment. Quarried material was selected to represent a fresh material (minimally weathered after detachment from the bearing rock), entering a fluvial system. Each clast was subjected to consecutive cycles of abrasion (starting from a 10-minute cycle) in the micro-Deval apparatus (Matest) (Figure 1a). The test in micro-Deval apparatus is an abrasion-wear resistance and durability test. The abrasion is produced by a combination of actions including friction, abrasion, and grinding in presence of water and steel abrasive charge (ASTM, 2017; BS EN, 2011).

The procedure used for the abrasion cycles in the micro-Deval machine was modified according to both, ASTM D6928-17 Standard Test Method for Resistance of Coarse Aggregate to Degradation by Abrasion in the Micro-Deval Apparatus (ASTM, 2017) and BS EN 1097-1:2011 Tests for mechanical and physical properties of aggregates - Determination of the resistance to wear (micro-Deval) (BS EN, 2011). At the beginning of each abrasion cycle, each clast was submerged in 2.0 L of fresh, tap water at ambient temperature (Figure 2a). It was decided to saturate the material before abrasion, so it would better represent the material that entered a fluvial system (in-stream material in transport, as well as the deposited material on gravel bars, etc). After saturation, 5.0 kg of steel balls (10 mm in diameter) was added to the micro-Deval drum, along with the water and a dolomite clast (Figure 2b). Afterwards, the clast was subjected to an abrasion cycle, at 100 revolutions per minute. Between the abrasion cycles (and in the initial state, before abrasion testing) each clast was oven-dried and weighed, and then analysed in Microtrac Camsizer XL.

Microtrac Camsizer XL (Figure 1b) is a dynamic image analyser that analyses materials' particle size distribution (if analysing material mixture) and size and shape of the analysed material. High-speed camera captures numerous images of particles at around 150 frames per second, while the software (PartAn 3D) analyses its' size and shape, combining 2D data of numerous image frames into a single 3D data set (Microtrac, 2021). Such analysis results in 33 size and shape parameters (e.g., surface area, sphericity, concavity, etc.).

Figure 1. a) Matest micro-Deval apparatus and b) Microtrac Camsizer XL

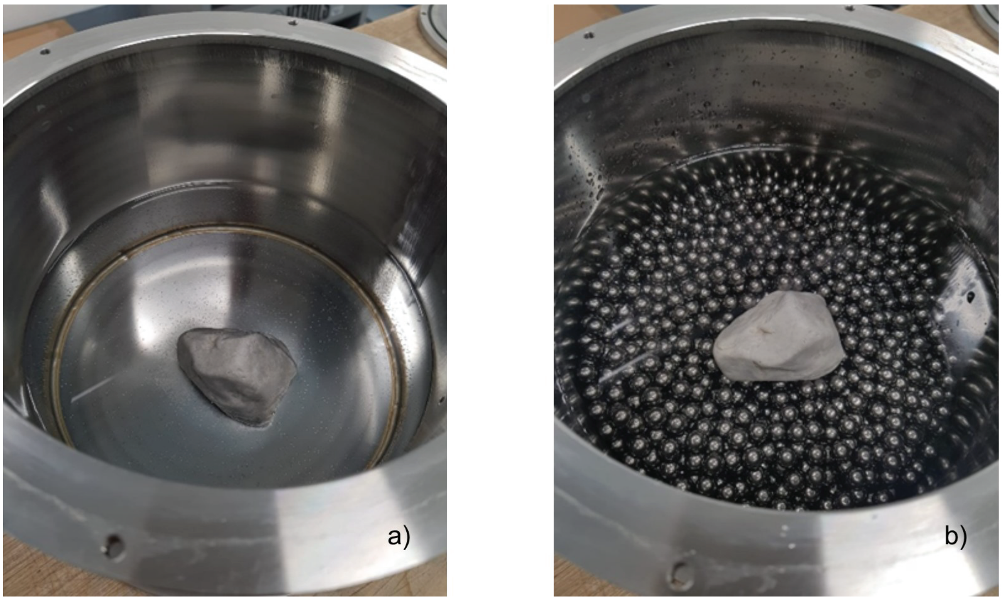

Figure 2. a) Saturation of a particle b) A particle prepared for the beginning of an abrasion cycle

3. IMAGE ANALYSIS (ANALYSIS OF DIA RESULTS)

Out of the resulting 33 parameters, 17 of them count for shape parameters. Out of all shape parameters, the most suitable ones to trace morphological changes of clasts due to abrasion were chosen according to the analysis of the resulting parameter values. Values of 2D parameters data of 3 measurement repetitions were analysed (results' scatter and coefficients of variation, CV%). The most suitable parameters were shown to be 'convexity' and 'sphericity' with CV% around 1% and 3%, respectively, of all the 2D data of the three repetitions of a single clast analysis for the observed natural material. Convexity is a measure of surface roughness (values between 0 and 1, with the value of 1 indicating a perfectly smooth surface), calculated based on the ratio of perimeter and convex hull perimeter. In the PartAn 3D software, it is calculated based on the average values of perimeter and convex hull perimeter values of the 2D image sequence. Sphericity is a measure of particles proximity to a circle (spheres projection) (values between 0 and 1, with the value of 1 indicating a perfect circle). In the PartAn 3D software, it is calculated based on the average values of area and perimeter of a 2D values of images sequence. 'Convexity' and its change were closer observed in the context of surface texture, while the parameter 'sphericity' in the context of shape - sphericity. Also, parameter 'angularity', in the context of particles' roundness was observed, regardless of its scatter, as the parameter is expressed as the maximum value of all 2D data values. Parameter 'angularity' describes the presence of sharp edges and corners on a particle, with values between 0 and 180 – where 0 represents a perfectly rounded particle, and 180 a particle with many sharp edges. On the other hand, parameter 'roundness' and 'concavity' showed the highest scatter, with CV% of over 13% and 20%, respectively. Roundness is a measure of particles proximity to a circle, calculated based on the area and the longest axis. Concavity is a measure of surface roughness, calculated based on the convex hull area and area.

Parameters chosen for observation of morphological changes – sphericity, convexity, and angularity were further investigated. The 3D data for sphericity and circularity was obtained as the average value of 3D values of three repetitions. Further, another set of 3D values of sphericity and convexity was obtained by taking 2D data of all frames of the three repetitions, then calculated to a single 3D data set. This 3D data set was calculated according to equations the software uses for calculating 3D data of each measurement. Eq. [1] and Eq. [2] show equations for convexity and sphericity, respectively (Microtrac, 2021). The analysis of obtained parameters' values showed the difference in sphericity and convexity values, obtained by 2 means, occurs from the 4th decimal place on. Hence, the data taken into consideration for observation of morphological changes was the averaging values of three repetitions' 3D data. As the angularity 3D value corresponds to the maximum value of all 2D frames, the value taken into consideration was the maximum value of the three repetitions' 3D data.

$$Convexity\ (3D) = \frac{Convex\ Hull\ Perimeter^{*}}{Perimeter^{*}} \qquad [1]$$

*average value of a sequence of images

$$Sphericity\ (3D) = \left[\frac{4\pi Area^{*}}{(Perimeter^{*})^{2}}\right]^{\frac{1}{2}} \qquad [2]$$

*average value of a sequence of images

4. PRELIMINARY RESULTS

Morphological changes of clasts were visible with the bare eyes and felt on touch already after a first 10-minute cycle. The clasts felt smoother and less angular. This change was enhanced with further abrasion cycles applied to the clast. The change in clasts' morphology after 6 abrasion cycles (cumulatively 120 minutes of abrasion) can be seen in Figure 3, showing two clasts in the initial state (before any abrasion cycles) and after the 6th abrasion cycle. The mass loss accompanying this morphological change, accounted for only 1.61 % (clast in Figure 3 a)) and 6.29% (clast in Figure 3 b)) of the original mass. Clasts in Figure 3 are concurrently the clasts with minimum and with maximum mass loss, from the tested clasts. The morphological changes are also visible in the output images from the PartAn 3D software, those are shown in Figure 4. In Figure 4, we can see two clasts (the same clasts as in Figure 3) in their initial state, after the second cycle of abrasion (cumulatively 20 minutes of abrasion) and after the 6th cycle of abrasion (cumulatively 120 minutes of abrasion), with markers added to the images for better orientation.

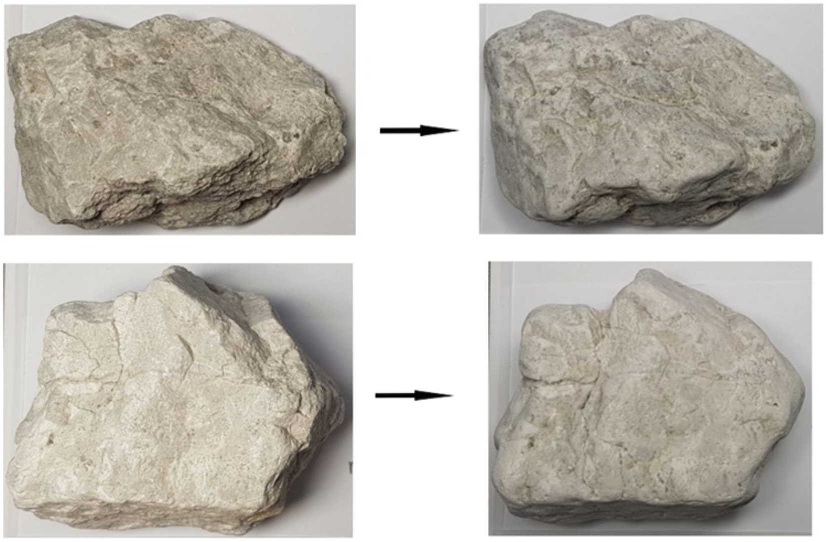

Figure 3. Example of particles at initial state and after 6 cycles of abrasion

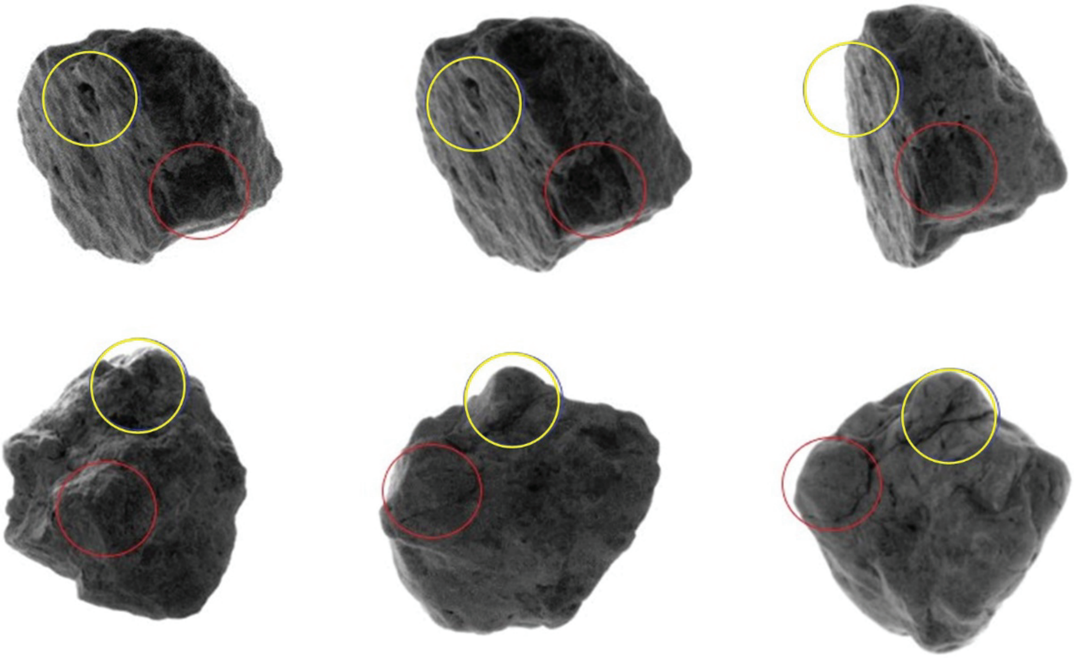

Figure 4. Example of particles' morphological changes after 2 and 6 cycles of abrasion

Preliminary results for the first 6 abrasion cycles are presented. The duration of abrasion cycles was 10 minutes for cycles 1-3, and 30 minutes for cycles 4-6. As the parameter analysis showed a negligible difference between analysis of all 2D data, compared to using 3D data output, the morphological changes of particles were described using 3D data values of the three repetitions. The selected parameters were 'convexity', 'sphericity', and 'angularity'. Values for 'convexity' and 'sphericity' were taken to be the averaging value of 3 measurements of the same particle (after each abrasion cycle), while for 'angularity' the absolute maximum value was observed, as well as the average value of the maximums of the three repetitions. The morphological changes are later observed as the average difference (change) in parameter value for all particles after each cycle in relation to the average cumulative mass loss of all particles.

With mass loss due to abrasion in micro-Deval apparatus, shape parameters' values recognised clasts getting in general smoother surfaces and becoming more rounded, with less sharp edges, which is in accordance with visual observance. The correlation curves and corresponding equations, between the cumulative mass loss and selected morphological parameters' change are shown in Figure 5 and Figure 6. All of the suggested correlations have the coefficient of determination (R^2) higher than 0.8, with the strongest R^2 for the logarithmic correlation between cumulative mass loss and the change in average maximum angularity. Only the correlation between cumulative mass loss and sphericity change showed a stronger linear correlation than logarithmic correlation, out of observed parameters. The proposed correlation curves for the change of clasts' morphological parameters, with the cumulative mass loss below 3% of initial mass, show similarities with those proposed by Cassel et al. (2018) for mass loss (up to 40%) and other shape (roundness) parameters of riverine pebbles.

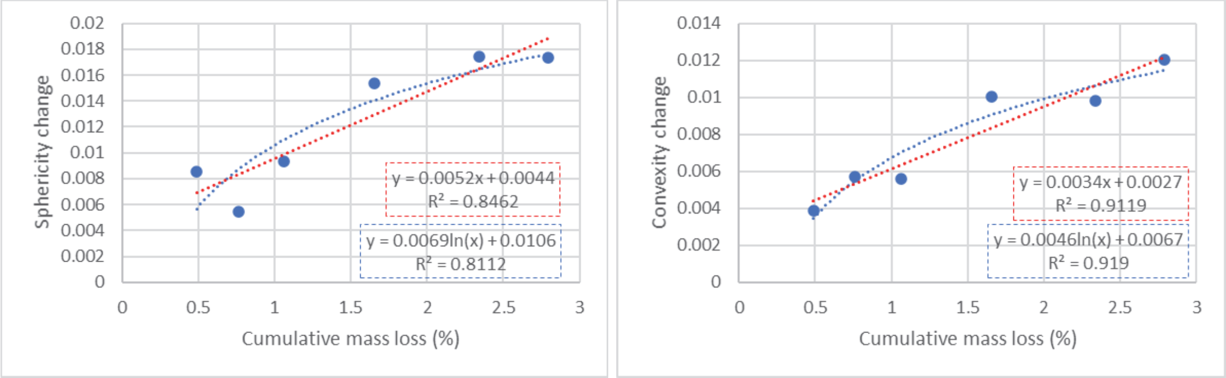

Figure 5. The correlation between the average cumulative mass loss (in % of the original sample) and a) average sphericity change (left), b) average convexity change (right).

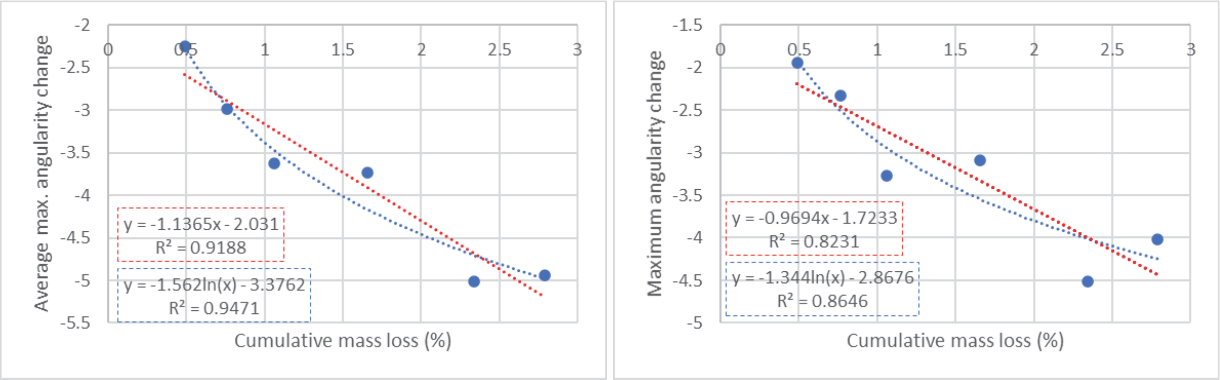

Figure 6. The correlation between the average cumulative mass loss (in % of the original sample) and a) average maximum angularity change (left), b) absolute maximum angularity change (right).

5. CONCLUSIONS AND FUTURE WORK

Dynamic image analysis offers a fast access to numerous size and shape factors, while conserving time spent for conventional, manual measurements. While generating numerous parameter results, it is of importance to recognize which of them are suitable for the description of phenomena of interest. It is important to understand the way of calculating each parameter, since terminology may be equivocal. But with the right interpretation of results, DIA is able to capture changes in morphology that are nearly impossible to measure manually.

For further work, more abrasion cycles are going to be carried out, reaching greater mass loss to observe further changes in clasts' morphology, with the aim of abrading the clasts to being 'perfectly' smooth as close as possible. A greater number of abrasion cycles and greater mass loss will enable the determination of more precise correlation curves between mass loss and changes in morphological parameters. In that way, it will be possible to determine how many abrasion cycles (abrading time) and mass loss of clasts' is necessary for the determination of adequately precise correlations, as the single clast testing is time-consuming, due to drying and analysing of each clast after each abrasion cycle.

6. ACKNOWLEDGEMENTS

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