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An alternative method for the particle size distribution: Image processing

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Abstract

Granular soils are used in different areas of civil engineering due to their easy accessibility and low cost as a material. The sieve analysis method, which has been conducted in rock physics measurements for many years, has been practicing determining the particle size distributions for those materials. In this study, a method based on image analysis technique has been developed as an alternative to traditional sieve analysis method for determining the particle size distribution in granular soils. This technique based on image processing to determine particle distributions via the experimental setup that consist of a camera, tripod, light box and mechanical shaking apparatus. In order to assess the reliability of this technique, each sample was subjected to traditional sieve analysis and the results of both analysis methods were compared. In conclusion, it was observed that the results obtained with the image processing technique had a minimum 95.22% closeness with the sieve analysis experiment data.

1. Introduction

Digital image processing method is simply the process of transferring the sample that willing to be analysed with an image capture instrument in a suitable format for digital media and by processing the raw image making it suitable for further analysis, and lastly collecting and storing the desired data. This method, whose foundations were laid with the examination of microscope images in the 1960s, has increased the areas of use day by day with the development of both computers and microscopes technologies. Digital image processing method has been used in many fields such as the analysis of cells, organelles, organisms in medical-based research, weather forecast in meteorology, the derivation of technologies such as fingerprint, retina scanning, night vision in the defence industry, tracking the habitats in environmental science, observing and controlling in industrial production lines [1-3].

Digital image processing technique within the scope of civil engineering has been used for various purposes since the 90's such as strength, permeability, compressibility of soils, shape parameters and deformations of materials, examining cross sections of concrete samples, measuring the maximum strength non-destructively, correlating the performance of coatings with the materials used. Obaidat [4], aimed to measure void ratios of mineral aggregates in bituminous mixtures using image processing mechanism and planimeter. Gaydecki et al. [5], proposed to find the location of the reinforcements in the reinforced concrete samples, in a non-destructive way through image analysis. Soroushian et al. [6], used digital image processing techniques to detect voids and micro cracks in the concrete sample. Soroushian and Elzafraney [7], studied the microstructure of concrete samples with the images they obtained with scanning electron microscopy and fluorescence microscopy. Felekoğlu and Güllü [8], scanned clinker samples using an optical microscope and performed areal phase and porosity distribution analysis with image processing techniques. Sinha and Fieguth [9], investigated the usability of image processing techniques to detect deformations in concrete pipes used as infrastructure elements and developed algorithms to detect deformations in underground concrete pipes that can work with image processing techniques. Park et al. [10], aimed to develop an algorithm that allows the detection of air gaps with image processing technique by examining the colored images of the polished sections of concrete samples.

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Granular materials are used in many areas due to their easy accessibility and low costs within the scope of civil engineering. They are being used as the main materials in both reinforced concrete and masonry structures, in addition to that they can be used for load transfer in steel and wooden structures. Concrete, one of the most common products, consists of aggregates between 60% -80% by volume, depending on the purpose of use. As result of that when evaluating the final strength of concrete, the importance of both physical and chemical parameters of the aggregate used reveals its importance. The wide area of usage of granular materials -in the scope of excavation / filling in various infrastructure and superstructure works, dam foundations and bodies, the leveling and filling area on bituminous hot-coated roads, applications such as jetcrete and grout in slope stabilization or tunnel applications- require the appropriate material selection. This selection happens with the help of a wide range of parameters such as specific gravity, chemical structure, mineralogical properties, permeability, cohesion values, internal friction angles [11-13]. The grain diameter size is the most common filter in making this kind of material selection. Sieve analysis method is used to determine the grain diameter distribution of grained materials. The sieve analysis, which has taken its final form today, is a universal method of classifying granular materials according to their size and weight. Testing procedures, that accepted by organizations such as ASTM, BS, AASHTO are being carried out with ISO standard equipment and instruments. The information which obtained from the sieve analysis results are the most important parameters in processing and classifying the grained material [14]. Some researchers have used image processing technique to determine grain diameter distributions as an alternative to the sieve analysis method, which can be described as relatively difficult and inconvenient. Yue et al. [15] studied the distribution, orientation and grain shape concepts of coarse particles in asphalt-added samples and concrete samples with the help of image processing technique. NG [16], studied the post-compaction microscopic structures of grained soils using the split element method. Masad and Button [17], examined the possibility of analyzing the grains' shape parameters with two different methods with using image processing technique by photographing the grained samples at different resolutions. Mora and Kwan [18], developed a method that analyzes the sphericity, convexity and shape parameters of the coarse aggregate using image processing technique. Yue et al. [19], used image processing techniques and the finite element method together to perform comprehensive analysis of two-dimensional shape of grained materials. Al Rousan [20], aimed to classify the grained materials according to their shape parameters with a computer-aided automation system. Alshibli and Alsalah [21], examined the sand soil samples under a microscope and statistically analyzed by their surface roughness, sphericity and roundness values. Yang [22], claimed that image processing researches in scope of soil mechanics were two-dimensional and aimed to make a three-dimensional analysis by filling the voids of the soil samples with epoxy. Hu et al. [23], researched the behavior of clay fillings under dynamic compaction using image processing techniques. Edizer [24], explained the image processing technique comprehensively and performed grain size analysis with this technique by using an open-source software. Sezer [2], used image analysis techniques to determine the microstructural properties of granular soils. Önal (2008), developed algorithms to directly use image processing technique in the scope of geotechnical engineering. Vangla et al. [25], claimed that digital image processing technique for size and shape analysis of sand particles would be more consistent than traditional sieve analysis method. Ehsan et al. [26], used image processing techniques for grain size analysis of granular soils. Dipova [13], arranged a new experimental setup to examine the grain distribution of grained soils with the image processing technique.

In this study, digital image processing technique has used as an alternative to sieve analysis method for the determination of the particle distribution in granular soils. In order to capture the images, an experimental setup has developed and images have taken to determine the particle distribution of samples of different volumes and different origins. The same samples have examined by sieve analysis method and the results of the two methods have compared. Inspired by the extensive literature study and its predecessors, the experimental setup was arranged in the light of the antecedent theories and it was aimed to conduct an experimental study. By using a simple mechanism and user-friendly software, a system that is compatible with automation and does not require the intervention and interpretation of the user has been designed.

2. Image Processing Technique

Digital image processing is the examination of the image captured within the scope of the intended analysis by using a processor. The sample to be analysed has transferred to the digital environment under suitable conditions, with a suitable tool that allows analysis, in the desired file extension, with the desired visual properties (brightness, resolution, colour, contrast, etc.). The tool should be capable of capture images such as digital or analog cameras, microscopes, telescopes, and video recorders and transfer the captured image to the analysing environment. The captured image could be filtered by parameters such as colour, brightness, contrast, sharpness, size, if necessary. The purpose of this process is to eliminate noises on image that occurs during or post-image capturing phase and to prepare optimized input for analysis. Analysis has performed by existing software or algorithms developed by the user. In subjects such as classification, measurement, statistical studies, database creation; It is essential to use a purposeful analysis algorithm in this method, which can be used for several fields such as medicine, genetics, industry, electronics, textile and space research. For example, since cell organelles were willing to be examined, it was necessary to capturing images in microscopic dimensions, in black and white or colour according to the purpose to examinate the organelle shapes or textures and making comprehensive and appropriate choices for correct analysis results [24,27-29].

Image processing technology is the conversion of data into various readable format and processing after capturing, measuring and evaluating. The concept of image is defined as a two-dimensional function in the format "f (x, y)". Here, x and y values are representing coordinates, while f function represents the intensity of the parameter [30].

It could be said that the different stages of the digital image processing process take place together or independently from each other, that different targeted methods may be created and associated with algorithms. The method, which allows working multidisciplinary, also allows to include desired available parameters to the analysis.

3. Particle Size Distribution

Particles that have evaluated within the scope of the soil mechanics could be examined with the help of a naked eye or a magnifying glass over a diameter of 0.075 mm, while particles above this diameter are considered as coarse materials. Particles smaller than 0.075 mm in diameter have classified as fine grains. It is possible to examine the particles between 0.075 mm and 2 µm in diameter with the help of a microscope. Particles with a diameter range of 2 µm to 0.1 µm could also be examined with a microscope, but for accurate analysis of the texture and shape parameters of the grains, it is recommended to examine the particles under 1 µm particle diameter by electron microscope. Examination of the molecular structure of the particles is possible with X-ray analysis [2].

The part of the soil that could be classified as coarse consists of sand and aggregates. While gravels, which has defined as rock particles, may consist of one or more minerals, sand particles generally consist of a single mineral, quartz. When the particles of sand and gravel have examined in terms of shape details, they were divided into five sub-groups; angular, semi-angular, semi-round, round, fairly round. Silt and clay particles may be angular, flat or needle shaped.

The sieve analysis method is a widely used technique for determining the particle size distribution of granular materials. By the particle size distribution information of the soil sample, it is able to gauge properties of soil such as the water permeability, strength, compressibility of the soil, determination of capillary water movements, frost effect, compression speed under load.

The sieves used in the sieve analysis consist of square grids of equally spaced wires. The aperture size varies inversely with the sieve number [31]. Sieve analysis starts with stacking of sieves one on top of the other in decreasing aperture order. The sieve set has shaken uniformly for 15 minutes, preferably with the shaking device. The sample remaining on each sieve has weighed separately after shaking process. Precise shaking time is needed, the short shaking process does not allow small particles to pass into the lower sieves, on the other hand the long shaking process may cause deformation of the particles and deflects the results [31].

Even though particle size distributions are determined by sieve analysis method, there were still some uncertainties about the shape of the grains. The size of a spherical particle may be described in one dimension; however, the grains' shapes in the soil sample are generally irregular, not uniform. In a sieve analysis test, the size of a particle is related to the size of the square apertures at mesh which the particle passes through. Since all axial sizes of a particle cannot be measured and the shape of the particle is not taken into account, the method also has some limitations [32-36].

4. Materials and Methods

4.1. Soil Samples

Six different test samples from four different origins have created for the study (Figure 1). The samples have obtained from different regions of Mersin province (Turkey). The first three samples have consisted of crushed stones taken from Mersin/Silifke region. Three different samples containing different particle diameter ranges have prepared by separating them manually. Thus, soil batches with the same surface and shape parameters have examined in different particle diameter ranges. Sample No.4 has prepared with crushed stone taken from Mersin/Toroslar region, and this sample's shape parameters and surface texture distinguish itself from the first three samples. Sample No.5 is a white-colored, grained material have taken from marble quarries in Mersin/Erdemli region. By using this material, also known as mosaic powder, the suitability of image processing techniques for analysis of different colored materials has been investigated. The sixth sample contains particles that could be regarded as more round, taken from the Mersin/Adanalıoglu region and has consisted of particles with lower unit weight and higher porosity than other samples. After the samples have grouped manually, they were washed and dried in a 110±5 degree celsius stove for 24 hours. After the drying process each sample has weighted and recorded as batch weight. The index properties of the samples are given in Table 1.

Table 1. The index properties of the samples

Sample No	D10 (mm)	D30 (mm)	D60 (mm)	Cu	Cr	Soil Classes
1	6.60	9.93	15.20	2.30	2.82	GP
2	0.57	1.45	2.08	3.65	0.28	SP
3	2.01	5.44	7.81	3.89	0.98	GP
4	4.31	5.72	7.94	1.84	2.24	GP
5	1.82	3.03	4.68	2.57	0.76	GP
6	1.29	1.86	3.02	2.34	0.49	GP

Figure 1. Samples prepared for the study

4.2. Particle Size Distribution with Image Processing

An experimental setup has developed within the scope of determining the particle distribution in granular soils by image processing technique. In the method, each sample whose weights have recorded was laid on a 60 * 60 cm lightbox. Images have captured with a Nikon D90 body, 18-55mm Vr Nikon lens with 4288*2848 resolution in 24 bits. Images have taken in dark room conditions with the help of a tripod by adjusting the height of the camera for proper framing (Figure 2). In order to prevent the contact and overlap of the particles in the sample laid on the lightbox, a shaking device has placed under the lightbox during image capturing, the photos were taken simultaneously by shaking the lightbox with a spring mechanism's impact. The image capturing setup has shown in Figure 3. All photos have taken at f/5.6 aperture, 1/1250 shutter speed, 105mm focal length and without flash. Denser samples have needed more than single shot for more accurate analysis. The number of shots taken for the samples and the number of particles analyzed in the samples have given in Table 2. In cases where more than one photo needed to be analyzed, the algorithm that used for single analysis has exported and rearranged to recall and analyze different photos sequentially. With a simple macro arrangement, it has ensured that more than one photograph was analyzed in a single sample, and results were obtained as a single document.

Image Pro Plus version 5.1.0.20 software has used for image processing. The first step in the program was opening the photograph to be analyzed from the program interface. A pixel to millimeter conversion has required in order to obtain the results in the metric system in the analysis made on the photograph. This requirement was met by an extra shot after a length measuring tool (ruler, tape measure, etc.) has placed on the lightbox. Unit distance-pixel conversion has performed using the measurement tool from the program interface. The opened photo was in 24-bit RGB format, but since 8-bit grayscale would be sufficient for analysis, reduction process has performed through the software. Afterwards, this grayscale photo has masked and reduced to a format that contains two values in the range selection that the program automatically assigns. Pixels above the entered threshold value and pixels below the threshold were separated and particles and the background has reduced to binary code. From the program interface, the values requested by the user were selected and outputs have obtained at the end of the analysis. MS Excel has used for further analysis in the study.

Table 2. Numerical information of the samples

Sample No	Weight (g)	Number of Grain	Number of Shot	Fmax (mm)	Fmin (mm)
1	1768.00	1459	2	41.418	2.580
2	158.42	121162	5	8.393	0.166
3	646.07	31507	4	22.050	0.500
4	1440.96	7987	5	27.404	0.478
5	326.71	17766	7	14.119	0.302
6	104.25	24217	5	18.823	0.401

Figure 2. Image acquisition environment

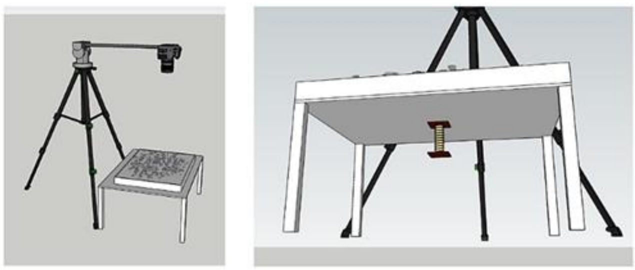

Figure 3. The setup for image capturing

Since the analysis was related to the particle size, the parameters have examined in the analysis are related to the size. The area covered by the particle in the photograph has examined in square millimeter. In addition, Fmax and Fmin values, which are the side lengths of the smallest size surrounding quadrilateral, were the parameters used in the analysis (Figure 4). The fact that the image was transferred to the digital environment in two dimensions and the reference experiment being a three-dimensional mechanical experiment have posed a problem that must be overcome for further comparisons. The data obtained by image processing were information covering two dimensions as shown in Figure 4. Researchers who have previously conducted similar studies have derived different correction coefficients using various parameters to make the method consistent [1,18]. Even if it was accepted that the particles of the sieves are limited by two axes, one more parameter has included in the analysis with the weight measurements made after the sieving process. Within the scope of this information, it was predicted that the data obtained from image processing, including two dimensions, may not be sufficient for an accurate dimensional analysis, and a new parameter has investigated [1,15].

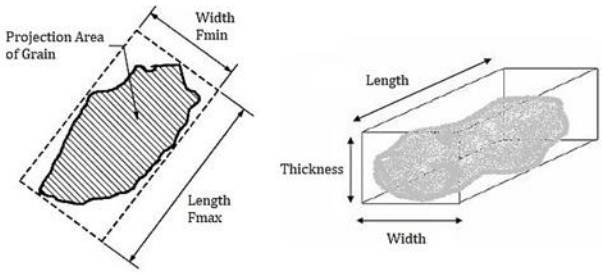

Figure 4. Image processing analysis parameters and display of three dimensions of particle [1,37]

Mora et al. [1] encountered the necessity of shifting the gradation curves for each sample when comparing the results of mechanical analysis and image processing. In this context, they ensured that the curves have approximated to the sieve analysis curves by assigning a "C" correction coefficient. The fact that the correction coefficient assigned here was at the user's initiative for each sample could lead to subjective errors. For consistent analysis this variable, which was not based on a constant and allows interpretation and abuse, have had to be excluded from the analysis [1,18].

The results were obtained from the image processing performed within the scope of the experiments in this study have included in the further analysis by using the raw data without using any correction coefficient. By following this method, the possibility of data interpretation and intervention has eliminated during processing. A value related to the shape (sphericity, angularity) and surface parameters of the particles has not been included in further investigations. This has led to the elimination of user intervention.

The obtained image processing data were filtered by accepting the hypotenuses of the meshes in the sieves as the limit, by using the standard sieve sizes. The aim here was to classify the particle diameters by using the sieve diameters and Fmax parameters, as in the process of weighing the materials remaining on the sieve in the sieve analysis. Theoretically this approach has made the comparison possible between image processing and sieve analysis in scale of sieve by sieve. By commenting on comparison results, evaluation of rate of success has been made.

$$\% \text{ Sieve Passing} = \frac{\sum_{i=1}^{p}(Area * F_{min})}{\sum_{i=1}^{n}(Area * F_{min})} \quad (1)$$

Calculations has made for each particle individually in all particle samples by using Equation 1, and then grading curves have drawn for all sample batches. In the equation, the projection area of the particle has multiplied by the value of Fmin and the possibility of adding a third dimension to the equation is examined and the results have evaluated.

4.3. Sieve Analysis

The samples have examined by image processing technique were subjected to the sieve analysis test with the traditional sieve analysis test procedure without any loss. The sieve analysis results have recorded with standard procedures and forms, and the gradation curves of the samples have drawn. Since the particle size distribution of the samples as different, the experiments have carried out by selecting the most suitable sieve set for each batch. The selection was made by the operator. The use of different sieve sets made it possible to compare and interpret the results of the image processing method in various diameters and grain distributions. Applications using sieve set, washing container, oven, scales and shaking devices have carried out in accordance with the descriptions and procedure given in TS 3530 [31].

5. Results

Both sieve and image processing results of 6 samples have obtained at the end of the study and the results have analyzed comparatively. While the gradation curves of the samples subjected to traditional sieve analysis have drawn following the standard procedure, the data related to the visuals examined with the Image Pro Plus software have transferred to the MS Excel program for further analysis. Grading curves were drawn by using MS Excel after filtering and basic calculations. The sieve analysis results have taken as a reference, and the results obtained by image analysis techniques have displayed on a single graphic to compare both curves (Figure 5-10).

6. Conclusion

In the scope of the study, an experimental setup has been designed to apply the image processing technique as an alternative to the relatively complicated and challenging sieve analysis method. As a result, the image processing technique, which could analyze without the need for sieve analysis equipment and laboratory, has yielded similar results to traditional sieve analysis. When the results have evaluated on the basis of sieves, a maximum absolute difference of 4.78% was encountered and the validity of the applied image processing technique has shown.

When the materials of different origins used in the study have examined in different diameters and volumes and compared with the traditional method, it has observed that curves consistent with the reference curves were drawn in all six samples. This proves that the image processing technique is valid for all the particles in different texture, color, unit weight and shape used within the scope of the research.

While the image processing method benefits the researcher from time and labor, the algorithms used were not valid for every sample and a repeat loop have has to be created for each sample. Nevertheless, this was not preventing the creation of a database according to sample types and transition to automation. In addition to the necessity of the presence of computers, cameras and lighting equipment, the researcher's has to be familiar and able to use of these equipment was another requirement.

It is possible to develop an automation for particle analysis with image processing techniques with a database created by statistical analysis including previous studies. With the developed automation, an experimental method which excludes user intervention and manipulation may be derived.

Sieve		Image Processing Results	% Passing	Absolute Difference
No.	Opening (mm)			
3/4"	19.000	100.00	100.000	0.00
5/8"	16.000	69.16	70.249	1.09
0.530"	13.500	49.32	50.339	1.02
3/8"	9.510	26.55	27.602	1.06
5/16"	8.000	17.59	18.213	0.62
1/6"	6.350	8.03	8.258	0.23
No. 5	4.000	0.00	0.000	0.00

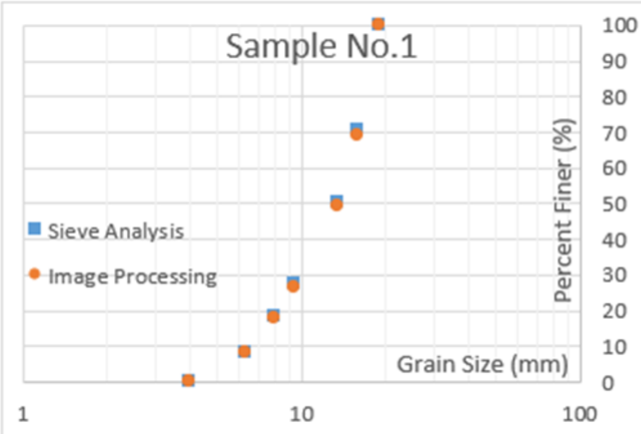

Figure 5. Comparison of results for Sample No.1

Sieve		Image Processing Results	% Passing	Absolute Difference
No.	Opening (mm)			
No. 5	4.000	100.00	100.00	0.00
No. 10	2.000	55.86	56.99	1.13
No. 12	1.680	36.72	37.26	0.54
No. 16	1.190	22.03	22.58	0.55
No. 20	0.841	15.35	16.11	0.76
No. 30	0.595	10.43	10.99	0.56
No. 35	0.500	5.60	6.29	0.69
No. 40	0.420	2.09	2.32	0.23
No. 50	0.297	0.00	0.00	0.00

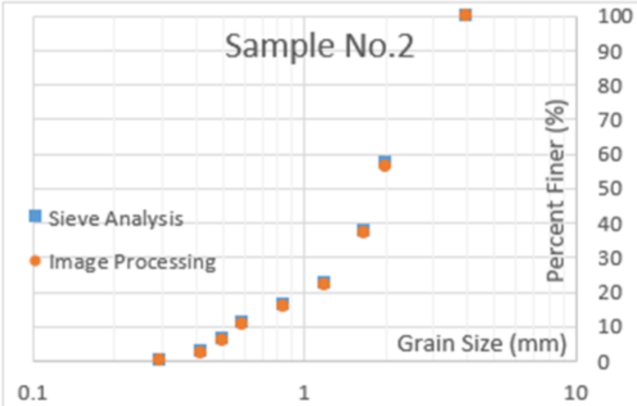

Figure 6. Comparison of results for Sample No.2

Sieve		Image Processing Results	% Passing	Absolute Difference
No.	Opening (mm)			
3/8"	9.500	100.00	100.00	0.00
5/16"	8.000	62.60	64.93	2.33
1/4"	6.350	33.69	35.72	2.03
No. 5	4.000	19.58	18.82	0.76
No. 10	2.000	11.87	10.05	1.82
No. 12	1.680	9.45	6.31	3.14
No. 16	1.190	5.27	3.71	1.56
No. 18	1.000	3.33	2.44	0.88
No. 20	0.841	1.67	1.37	0.30
No. 30	0.595	0.79	0.61	0.18
No. 35	0.500	0.00	0.00	0.00

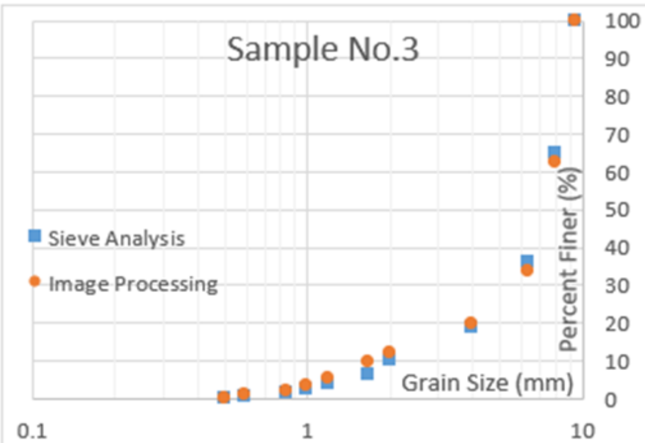

Figure 7. Comparison of results for Sample No.3

Sieve		Image Processing Results	% Passing	Absolute Difference
No.	Opening (mm)			
0.530"	13.500	100.00	100.00	0.00
3/8"	9.500	82.18	81.64	0.54
5/16"	8.000	62.68	61.79	0.89
1/4"	6.350	39.45	38.87	0.58
No. 5	4.000	5.22	5.09	0.13
No. 10	2.000	0.69	0.70	0.00
No. 12	1.680	0.43	0.45	0.02
No. 16	1.190	0.13	0.14	0.01
No. 20	0.841	0.00	0.00	0.00

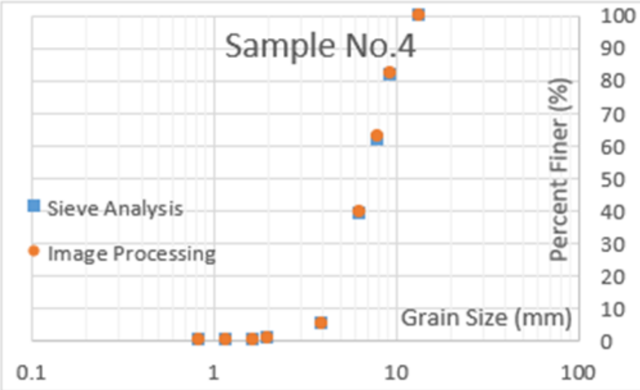

Figure 8. Comparison of results for Sample No.4

Sieve		Image Processing Results	% Passing	Absolute Difference
No.	Opening (mm)			
5/16"	8.000	100.00	100.00	0.00
1/4"	6.350	97.20	97.69	0.49
No. 5	4.000	35.63	40.27	4.63
No. 10	2.000	10.45	14.08	3.62
No. 12	1.680	5.49	7.84	2.35
No. 16	1.190	2.57	3.91	1.33
No. 20	0.841	0.66	1.05	0.39
No. 35	0.500	0.00	0.00	0.00

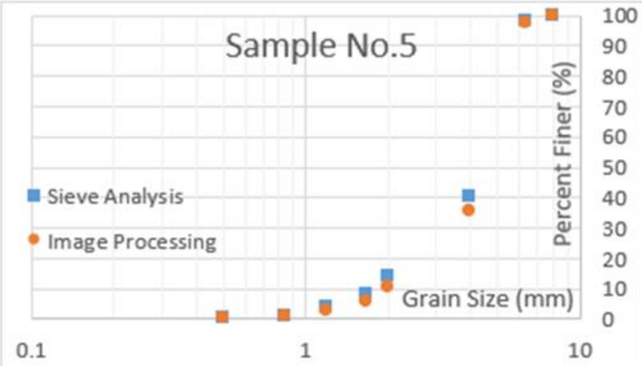

Figure 9. Comparison of results for Sample No.5

Sieve		Image Processing Results	% Passing	Absolute Difference
No.	Opening (mm)			
5/16"	8.000	100.00	100.00	0.00
1/4"	6.350	91.28	93.90	2.62
No. 5	4.000	73.81	74.92	1.11
No. 10	2.000	34.43	38.56	4.13
No. 12	1.680	18.05	22.83	4.78
No. 16	1.190	6.37	9.77	3.40
No. 20	0.841	1.30	2.27	0.97
No. 35	0.500	0.00	0.00	0.00

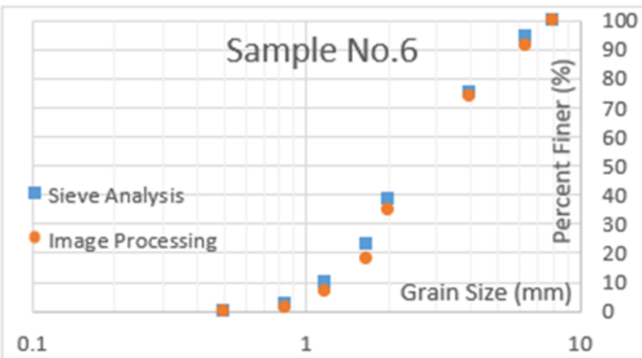

Figure 10. Comparison of results for Sample No.6

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Author contributions

Mert Aydin: Methodology, Software **Talas Fikret Kurnaz:** Writing-Original draft preparation, Investigation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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