SIMPLIFIED APPROACH FOR THE STATISTICAL CHECK OF STONE AGGREGATE SUPPLY BY MEANS OF IMAGE ANALYSIS METHOD

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ABSTRACT

The petrographical type is the first reference that is taken into account in stone aggregates supplying for road construction and, in particular, for the manufacturing of asphalt concretes. This characteristic is evaluated by means of a chemical-physical analysis on representative samplings.

With the aim of optimizing the check procedures of stone aggregates supply for asphalt mixes, the technological evolution prefigures the use of systematic and quick control systems, that are able to limit the samples number to be analysed in laboratory.

The image analysis techniques may represent an interesting aid for a first level check of stone aggregates samplings. These techniques are based on the principle of aggregates colour identification, taking into account the chromatic shades and the inevitable unhomogeneity typical of natural materials for constructions.

In this paper it is exposed a procedure of image analysis characterized by simple approaches and based on the employment of widely diffused software. This procedure allows to classify crushed stone aggregate samples according to the relative chromatic coordinates, that becomes a parameter of statistical control of the homogeneity of the single supply and the possible different assortments.

Keywords: mineral aggregate, image analysis, quality control.

1. INTRODUCTION

The petrographical type is the first reference that is taken into account in stone aggregates supplying for road construction and, in particular, for the manufacturing of asphalt concretes.

Shape indicators, microtexture and mechanical resistance measurements allow to preliminarily qualify stone aggregates in order to assure the best performances of asphalt concretes in the different employment in the road structure. Further checks on stone aggregate mixes are needed to verify the quality and the homogeneity of supply arrived at the mixing plant. Moreover, there is a subsequent check phase on samples taken from the finished road pavement, that is carried out after the binder extraction.

With the aim of optimizing the aggregates check processes for asphalt mixes, the technological evolution prefigures the use of systematic and quick control systems, that are able to limit the samples number to be analysed in laboratory.

The image analysis techniques may represent an interesting aid for a first level check of stone aggregates samplings. These techniques are based on the principle of aggregates colour identification, taking into account the chromatic shades and the inevitable unhomogeneity typical of natural materials for constructions.

An image analysis procedure is developed using simple approaches and based on the use of a widely diffused software. This procedure allows to classify crushed stone aggregate samples according to the relative chromatic coordinates, that becomes a parameter of statistical control of the homogeneity of the single supply and the possible different assortments.

The investigation carried out in laboratory has the target of validating an experimental procedure that, analyzing images obtained from stone aggregate samples, is able to qualify and quantify the kind of the aggregate into the mix for the manufacturing of asphalt concrete.

2. PRODUCTION OF STONE AGGREGATE IMAGES

With the clear aim of simplifying the stone aggregate kind identification by means of the colour interpretation of pictures or images taken through scanner, two stone aggregate supply have been used in the investigation. The stone aggregates have substantially different colour and mineralogical nature: basalt (dark colour) and limestone (bright colour). The employment of these two kind of stone aggregate allows the clear distinction, in terms of images and colour, between materials and therefore an effective calibration and an easier verification of the proposed method.

To obtain images exclusively of the aggregate, that are used in the calibration of the analysis method, samples of stone aggregate have been manufactured using transparent binder (two-components colourless epoxy resin, particularly suitable for realisation of pouring and englobing). The final result is a solid cylinder made of stone aggregates bounded by transparent binder that allows the handling of samples visually analysable and easily dissecting.

In detail, series of three samples have been manufactured using fixed percentages of stone aggregate of the two different colours (Table 1). The cylindrical samples are 100 mm high and 100 mm diameter.

The size of the single stone grain is always between 5 and 10 mm.

Table 1 Employed percentage of stone aggregates

samples	% basalt	% limestone
A1-A2-A3	0	100
B1-B2-B3	100	0
C1-C2-C3	50	50
D1-D2-D3	75	25
E1-E2-E3	25	75

The aggregates have been compacted by means of a flow table (50 blows) and then saturated pouring the colourless epoxy resin.

To avoid the creation of air bubbles in interstices between aggregates, the epoxy resin has been poured along the inner side of the cylindrical container. In this way the air between the aggregates could go up again to the surface, pushed by the resin.

The samples have been left at air temperature for hardening in a place protected by sunbeams to avoid the resin early yellowing. After 24 hours from the manufacturing, the samples have been sliced in thin sections, 15 mm high, by means of a rock shearing machine.

The surfaces of the thin sections have been subjected to digital scanning to obtain photograms easy to manage (images in bitmap format, 240x227 pixel, 99 dpi).

3. IMAGES ANALYSIS

The employment of image analysis processes in the study of bituminous concrete developed most of all for the measurement of characteristics as angularity [Masad, E. et al., 2000], shape [Lin, J.D. et al., 2004], grading distribution and orientation in aggregates mix [Hammoum, F. et al., 2003; Hammoum, F. et al., 2004], the surface texture [Masad, E. et al., 2004]. The images analysed in these studies are taken by scanner or digital camera and they are usually acquired and treated in black and white or in grey scale.

In the experimental investigation carried out, a specific software for images acquisition and elaboration has been used [Matrox Inspector 4.0®]. This software allows an in-depth study of colour images.

The software allows to mark out into the image a line of known initial and final coordinates (“measure line”- punctual method) and therefore it calculates, for each point of the line, the colour components (Figure 1 and Figure 2).

The results are summarized in a graph that shows on the abscissa the coordinates of measure line (x or y) and on the ordinate the value of the colour corresponding to the defined pixel on RGB scale, from 0 (value corresponding to black) to 255 (value corresponding to white). In the graph there are three curves that represent the three primary components of the RGB (Red, Green and Blue) colour model.

The calibration by means of measure lines allows to obtain a gap of colour values where it is possible to identify a specific kind of aggregate. The analysis has been carried out on the images obtained from the scanning of the thin sections of samples made with 100% limestone or 100% basalt, marking out a grid of measure lines (spaced 20 pixels) to obtain the colour values of the pixels representative of the whole image.

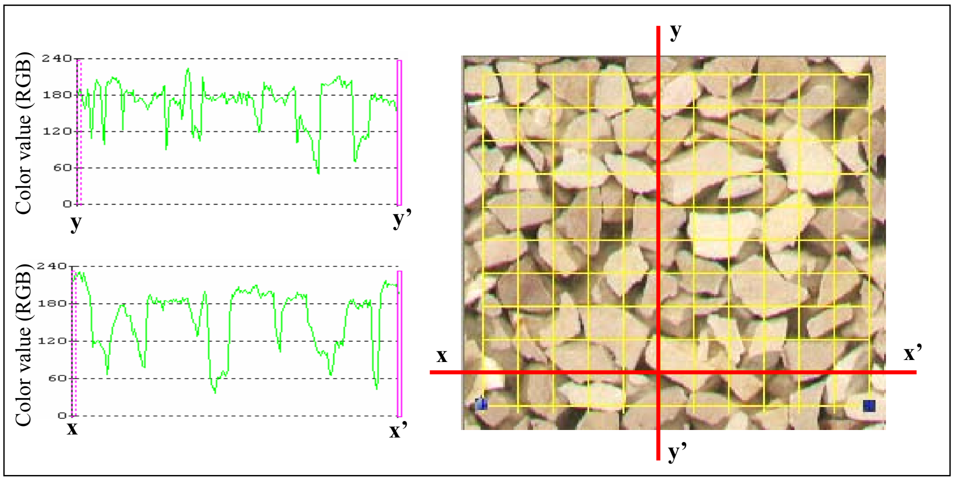


Figure 1. Measure lines on sample A1.

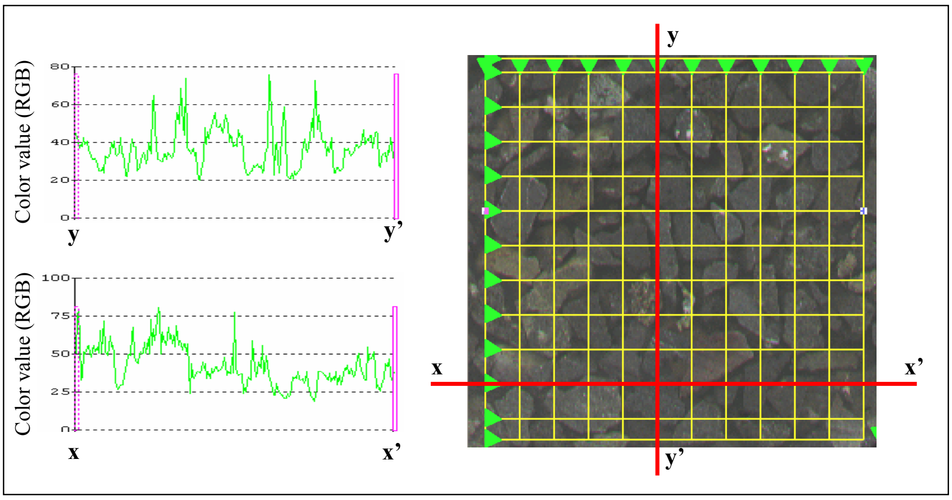


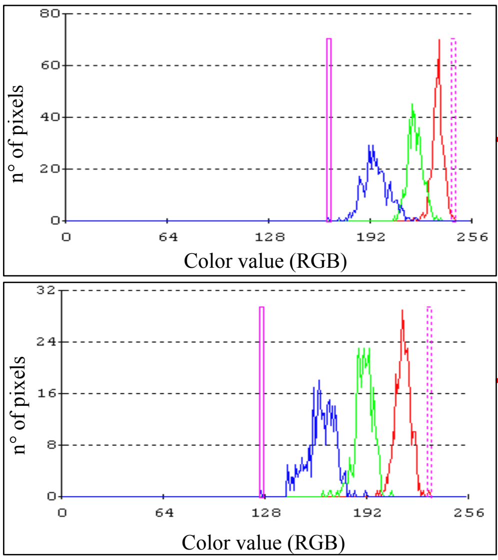
Figure 2. Measure lines on sample B1.

In this study only the green component of the three RGB colour model components in the graph has been taken into account. The sensibility to the green (λ=546,1 nm) of an observer is coincident with the "visibility curve", that is the maximum sensibility of the human eye for the wave length in the middle of the visibility field (wave length between 400 and 700 nm) [Moncada Lo Giudice, G. et al., 2002].

Taking into account that red is characterized by λ=700 nm and blue by λ=435,8 nm, the choice of green as the best recognizable component also for low colour levels is justified.

Beside this kind of analysis, the software is able to study small areas of the image, selected by the user, and to provide an histogram representative of the three components of the RGB colour model.

The graph corresponding to this analysis shows on the abscissa the colour values referred to the pixels in the selected area and on the ordinate the number of pixels for each colour value (Figure 3 and Figure 4).



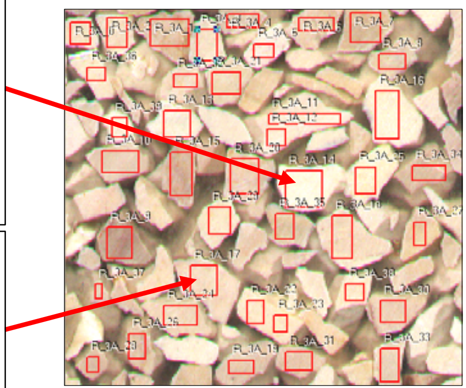
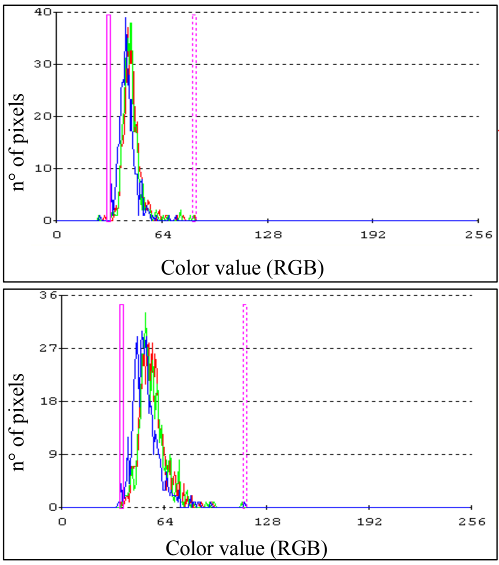


Figure 3. Analysis area on sample A1.



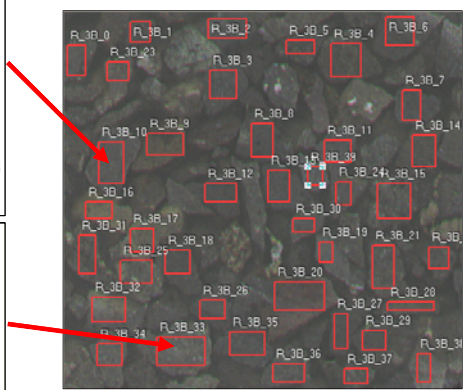


Figure 4. Analysis area on sample B1.

The calibration by means of values relative to small areas of the image has been carried out on areas selected by the user. The choice of the area to be analysed has been done selecting only areas of the image where the aggregate is on the first level, uniform, avoiding areas where there are shadows or where the aggregate is behind the resin.

Moreover the whole image has been analysed elaborating an histogram of the number of pixels for each colour value, that is the distribution of the colours according to the values of RGB chromatic scale. The graphs obtained by the analysis of the whole image represent the three curves of colour components of RGB model. Also in this case, for reducing the investigation field, only the green component of the colour model has been considered.

Graphs show on the abscissa the values of colour and on ordinate the number of pixels for each colour value (Figure 5 and Figure 6).

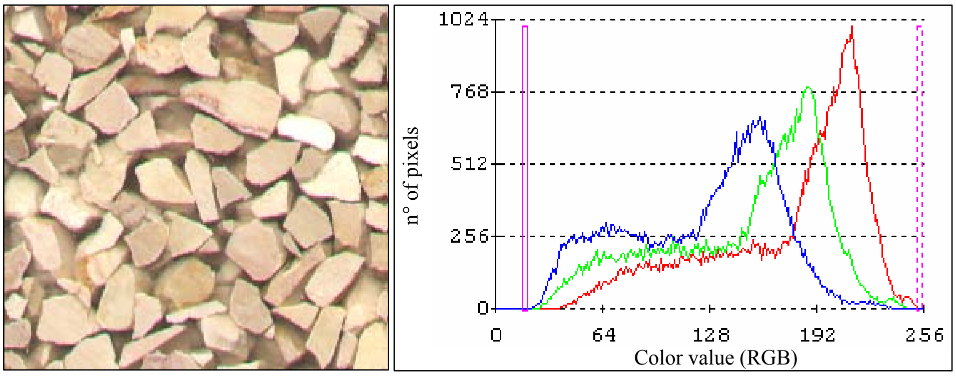


Figure 5. Histogram of the whole image of the thin section of sample A1.

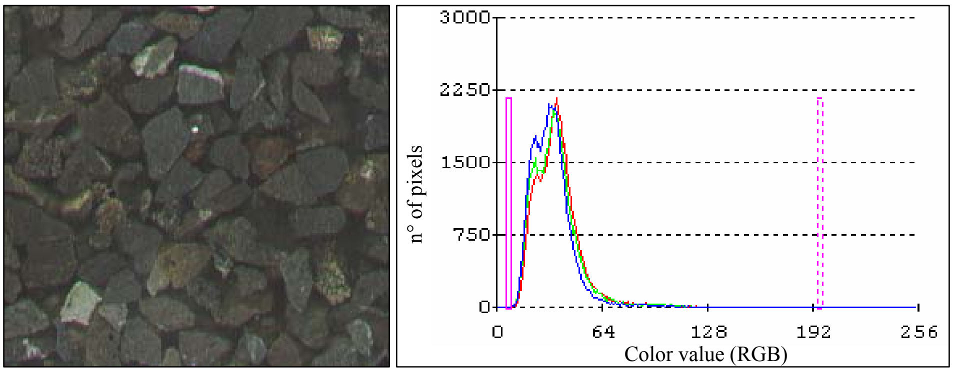


Figure 6. Histogram of the whole image of the thin section of sample B1.

4. RANGE OF VARIABILITY

With the aim of obtaining a colour gap to be assigned to each aggregate kind, a statistical study has been carried out on the data of the whole images colour using 17 photograms for each type.

From each image an histogram has been obtained, where are shown the frequencies in function of the colour values from 0 to 255 of RGB model. The mode has been chosen as the best representative value of the population. The average of the modes ($\overline{X}$) and the standard deviation (σ_x) have been calculated for the limestone aggregate and for the basaltic aggregate and the gap Δ has been fixed. Δ is the interval in which it is possible to find, with a probability of 90%, the values that really correspond to the limestone or basaltic aggregates, applying to the standard deviation the multiplicative factor t (from tables for the confidence interval estimation) for the confidence α=10% and for n-1=16 degrees of freedom.

The values are shown in table 2.

Table 2 Colour values (RGB) calculated for the two aggregate kinds

	Limestone	Basalt
$\overline{X}$	186,94	35,65
σ_x	5,93	2,03
Δ	187±10	36±4

The fixed Δ have been used for calculating the percentage of limestone and basalt in manufactured samples.

The software for the recognition of colour has defined in the images of the different samples the percentage by volume of limestone and basalt (table 3).

Table 3 Values calculated by the software

Samples	% Limestone calculated	% Basalt calculated
A	24,44	0,90
B	0,01	31,36
C	10,79	16,82
D	5,02	19,52
E	17,28	9,51

The employment of image analysis techniques needs an in-depth statistical study on samples and model. The study carried out is briefly summarized in scheme in figure 7.

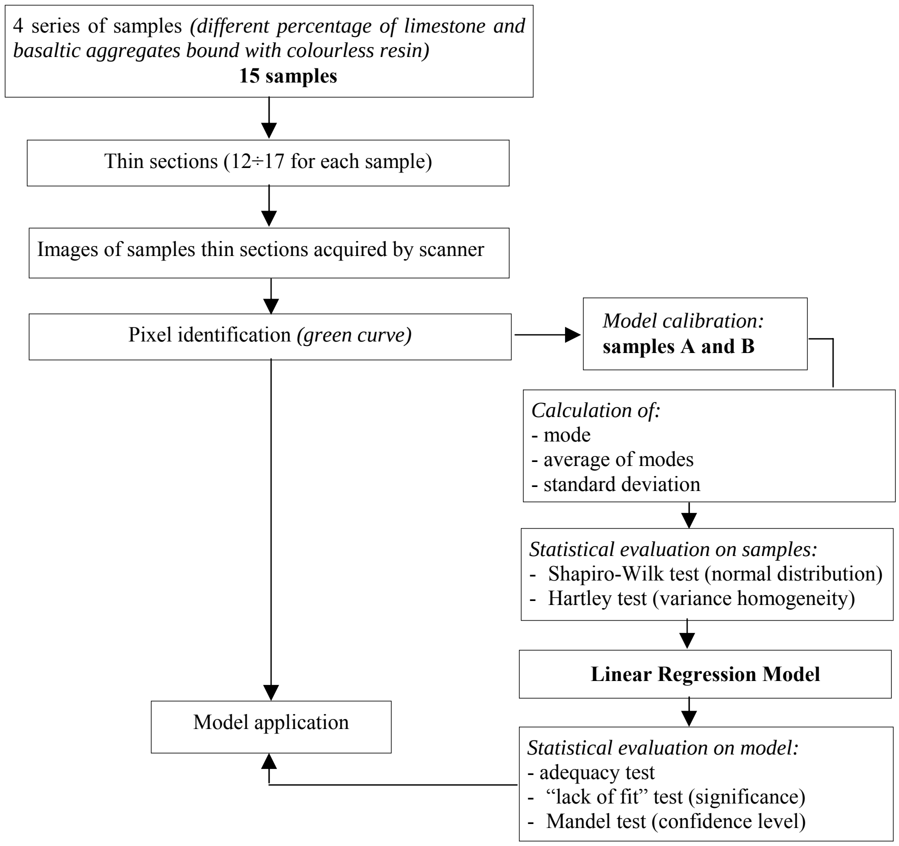


Figure 7. Scheme of the experimental investigation.

5. VERIFICATION OF CONDITIONS FOR THE CONSTRUCTION OF THE MODEL BY MEANS OF MIN SQUARE METHOD

The acquired data have been revised obtaining the best linear correlation model existing between the aggregate percentage read by the software and the real percentage used for samples manufacture. First of all a verification of some conditions needed for the model validity has been carried out.

The first condition that has been verified is that the n values set used for the model construction belong to n different normal distribution. Then Shapiro-Wilk test has been carried out. It highlights for the basaltic aggregate the variance homogeneity for the five levels and it is possible to proceed to the calculation of the regression model (Table 4).

About the limestone, the measures set does not belong to a normal distribution. For this fact, the point corresponding to the white concentration of 0% is not used in the calculation of the linear regression model.

Table 4 Shapiro-Wilk test for the basaltic aggregates (* measures=17; α=0,05)

% basalt	$S_{w\ calc}$	$S_{w\ tab\ *}$	$S_{w\ calc} > S_{w\ tab}$ (linear relationship)
0	0,931	0,892	verified
25	0,955	0,892	verified
50	0,905	0,892	verified
75	0,970	0,892	verified
100	0,951	0,892	verified

Table 5 Shapiro-Wilk test for the limestone aggregates (* measures=17; α=0,05)

% basalt	$S_{w\ calc}$	$S_{w\ tab\ *}$	$S_{w\ calc} > S_{w\ tab}$ (linear relationship)
0	0,581	0,892	not verified
25	0,968	0,892	verified
50	0,956	0,892	verified
75	0,975	0,892	verified
100	0,910	0,892	verified

A further condition that has to be verified before the calculation of the regression model using the min square method, is the variance homogeneity on the whole studied interval. For this purpose the Hartley test has been used.

This test has been applied for the limestone aggregate to the data set corresponding to 25%, 50%, 75% and 100%, while for the basaltic aggregate it has been applied for all the five concentration levels, after a variables transformation (considering the transformation in square root of the variables). The results are shown in table 6.

Table 6 Hartley test (*α=0,05; d.o.f. numerator=16; d.o.f. denominator=16).

Aggregate	F_{calc}	F_{tab*}	$F_{calc} < F_{tab*}$ (homogeneous variance)
Limestone	2,312	2,333	verified
Basalt	1,283	2,333	verified

Once the normal distribution and the variance homogeneity have been verified, the linear regression model has been calculated (Figure 8 and Figure 9). In the linear regression equation y=A+Bx the variable x represents the real percentage and the variable y the percentage calculated by the software (and the respectively square root for the basaltic aggregate).

On the regression line, after the verification of the condition of variance homogeneity, the statistical tests for the adequacy of the model, the “lack of fit” and the Mandel test have been carried out. The results are shown in tables 7, 8 and 9.

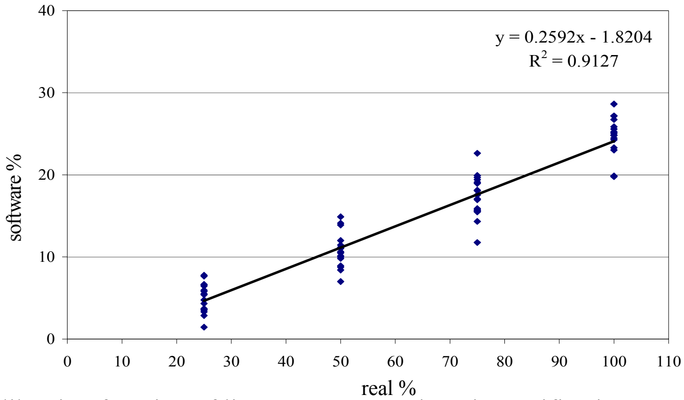


Figure 8. Calibration function of limestone for the linearity verification.

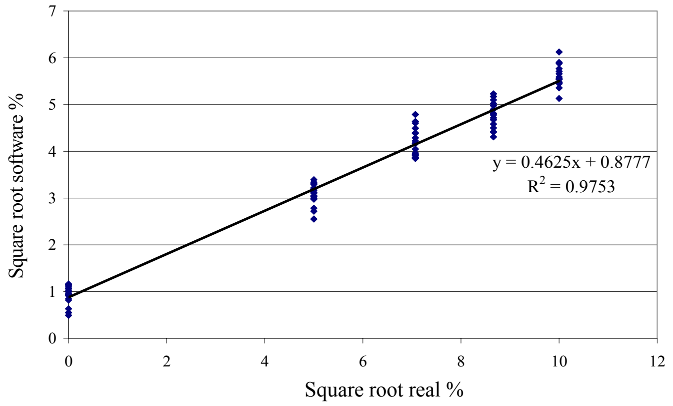


Figure 9. Calibration function of basalt for the linearity verification (considering the transformation in square root of the variables).

Table 7 Model adequacy test (*α=0,05; d.o.f. numerator=1; d.o.f. denominator=66)

Aggregate	F_{calc}	F_{tab*}	$F_{calc} > F_{tab*}$ (suitability of regression model)
Limestone	700,249	3,982	verified
Basalt	3172,915	3,982	verified

As can be seen from results, the models are adequate for describing the relationship between x and y, with a confidence level of 95% for both the aggregate kinds.

Table 8 "Lack of fit" test (*d.o.f. numerator=2; d.o.f. denominator=66)

Aggregate	F_{calc}	F_{tab*}	α	$F_{calc} < F_{tab*}$
Limestone	1,179	3,136	95 %	verified
Basalt	3,989	4,953	99 %	verified

From data it is evident that the linear model deduced for the limestone aggregate is adequate for describing the relationship between x and y with a significance higher than 0,05, while for the basaltic aggregate, the chosen linear model is adequate with a significance higher than 0,01.

Table 9 Mandel test (* α=0,05; d.o.f. numerator=2; d.o.f. denominator=66)

Aggregate	F_{calc}	F_{tab*}	$F_{calc} < F_{tab*}$
Limestone	0,878	3,984	verified
Basalt	3,788	3,984	verified

From data it is possible to assert that, with a confidence level of 95%, in both cases, the linear regression model is better than quadratic regression model for describing the distribution of experimental data.

6. APPLICATION OF THE METHOD

The linear regression models that have been calculated and verified, have finally been applied to the study on independent samples, that have not been used for the determination of the models themselves, using samples manufactured with fixed percentages of basalt and limestone.

In table 10 are shown, for example, data obtained from the image analysis on a sample made with 50% limestone and 50% basalt (sample type "C"), the obtained values have been made uniform considering the sum of the two percentage as 100%.

The validity of the model is confirmed by the values of the final average of the two different aggregates that are obtained by means of the software of image elaboration: they are very similar to the percentages really employed in samples manufacture.

Table 10 Method application on a sample type "C"

Average on the sections	% Limestone	% Basalt
X1	61,85	38,15
X2	55,90	44,10
X3	53,26	46,74
X4	43,28	56,72
X5	63,07	36,93
X6	39,24	60,76
X7	41,46	58,54
X8	51,53	48,47
X9	47,79	52,21
X10	44,66	55,34
X11	26,40	73,60
X12	59,93	40,07
Xm	49,03	50,97

7. CONCLUSIONS

The proposed technique is based on an exclusively experimental approach and applies the image analysis method on photograms of stone aggregate samples appropriately manufactured.

The image analysis allows to distinguish between the different colour of the single stone aggregates in the mix and is able to go back up the percentages of the different stone aggregate kinds used.

In the experimental investigation, carried out on stone aggregate samples bound with transparent resin, the reading and analysis ability of the system for images elaboration have been calibrated. The system is suitable to translate the information of each single pixel in a numerical data to be elaborated.

The protocol resulting from the experiences carried out allows to consider the statistical results reliable, due to the good data and to plan an analysis technique in real scale quick and useful.

The obtained models give substantially a good description of the phenomenon. Indeed the defined regression models led to an excellent correspondence between real percentages used for samples manufacture and calculated percentages obtained by the elaboration of data of images analysis on the same samples.

REFERENCES

HAMMOUM, F., BERTAUD, V. and BONNET, P. (2003) – “ Identification de la structure interne des materiaux routiers par analyse d’images” – *Journees des Sciences de l’Ingenieur du Reseau des Laboratories des Ponts et Chaussees - LCPC*, Dourdan, France.

HAMMOUM, F., and HORNYCH, P. (2004) – “Quantitative study of bituminous materials microstructure by digital image analysis” – *Proceedings of the 3rd Eurasphalt & Eurobitume Congress*, Wien, Austria.

LIN, J.D., CHEN, S.H., ZUNG, C.C., LIU, P. and HUNG, C.T. (2004) – “The study of digital image process technique on the analysis of asphalt concrete” –*Proceedings of the 3rd Eurasphalt & Eurobitume Congress*, Wien, Austria.

MASAD, E., BUTTON, J.W. and PAPAGIANNAKIS, T. (2000) – “Fine aggregate angularity: automated image analysis approach” – *Proceedings of the 79th Annual Meeting - Transportation Research Board*, Washington D.C., US.

MASAD, E., LITTLE, D., and SUKHWANI, R. (2004) – “Sensitivity of HMA performance to aggregate shape measured using conventional and image analysis methods” – *International Journal of Road Materials and Pavement Design, Vol.5 , 4/2004,* pp. 477-498.

MATROX INSPECTOR 4.0®. Matrox Electronic Systems Ltd. Dorval, Quebec, Canada.

MONCADA LO GIUDICE, G. and DE LIETO VOLLARO, A. (2002) – *Illuminotecnica* – Casa Editrice Ambrosiana, Milano, Italia.