Correlation of digital images with the deterioration characteristics of quarried limestone in Egypt

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Abstract: The aim of the project was to determine whether there is a correlation between colour changes recognized in digital image processing and the deterioration properties shown by the limestones used in the ancient monuments of Cairo. 12 samples of limestone extracted from ancient quarries around Cairo known to be the principal sources of the monument stones were selected for analysis. A comparative study was then made between the fresh sample state, before being subjected to by any environmental changes, and the final state after being exposed to a rapid chemical weathering procedure, designed to resemble exposure to a long period of poor environmental conditions. The aim was determine whether a relationship exists between deterioration in the color spectrum shown by the samples and deterioration in their physical and mechanical properties.. This will provide a method for using deterioration in color system by digital photography to predict quantitatively the deterioration in physical and mechanical rock properties and thus predicting precisely degree and method of remedial treatment needed for the stonework. The results obtained indicated that percentage of color deterioration is very closely related to deterioration of porosity (R^2 = 1), then to deterioration of compressive strength (R^2 = 0.9) then to density (R^2 = 0.8).

Résumé: Une technique de traitement des images numériques a été appliquée afin d'évaluer la détérioration des roches calcaires. Une série de 12 échantillons a été prélevée des anciennes carrières autour du Caire puis a été exposée aux variation accélérées de conditions climatiques dans une chambre de simulation. L'étude comparative de cette démarche a pour but de quantifier le rapport entre les changements de couleurs des échantillons, à travers des séries d'images numériques, et la dégradation des caractéristiques physiques et mécaniques de roche. Cette technique a démontré que la détérioration des couleur de la roche et proportionnelle à ses caractéristiques, tels que : la porosité (R^2=1), la contrainte positive (R^2=0,9) et la densité (R^2=0,8).

Keywords: Environmental impact, expansion, fractures, weathering, deterioration, image analysis

INTRODUCTION

In the earlier stages of our research project entitled " Determination of monument stone durability by using digital image processing" , the results obtained for stone durability were in absolute form. These results then needed to be validated by developing a standardized laboratory procedure.

One method of determining the durability of stone would be to subject it to a cycle of operations corresponding to the action of different weathering agents, acting at strengths many times those attained in practice, in order to produce, in days or weeks, results similar to those which would occur naturally over a period of years (Brand, 1990**;** Fookes and Hawkins; 1988; Martin and Hencher, 1986**;** Olivier, 1979 and Derman, 1976).

In this present stage of the research project, the results obtained from the proceeding phases were applied on samples of limestone extracted from ancient quarries around Cairo. A comparative study was then made between the samples in a fresh state, before being affected by any environmental changes, and the final state, after being exposed to a rapid chemical weathering, resembling exposure to a long period of very polluted environmental conditions. The results were used to try to find a relationship between deterioration in color spectrum of the samples and deterioration in physical and mechanical properties of studied limestone samples. This will help, in the development of a non-invasive methodology, using deterioration in color spectrum by digital photography, to predict quantitatively the deterioration in physical and mechanical properties of a rock. If successful such a procedure could also be used to more precisely predict the degree and method of remedial treatment to the stone that is likely to be needed.

METHODOL0GY

Four stone samples taken from four stone quarries around Cairo known to be the source of monument stones namely Al- Rafaii (L1); Dahshour (L2); Helwan (L3) and Mokattam (L4) are to be studied in this phase of the research project.

A methodoloy was established to correlate degree of deterioration determined by digital images and degree of deterioration after the exposure of samples to artificial chemical weathering by immersing it in acidic water and drying it for periodic cycles as follows (ISRM, 1981):.

- Preparation of three cubes (5 x 5 x 5 cm)of each type of limestone from the following sites:
  - - Al- Rafaie (L1)
  - - Dahshoor (L2)
  - - Helwan (L3)
  - - Mokattam (L4)
- The following tests on the 3 cubes were then performed:
  - Digital photographing of the first cube in its fresh state. Carry out initial physical properties tests on the fresh sample cubes to determine dry density **(γ_i)** and porosity **(n_i values)**
  - Determination of mechanical properties of the second cube including compressive strength **(σ_i)**.
  - Determination of acidic durability for the third cube by exposing the samples to 5 periodic cycles of immersion and drying using acidic water (1 N of H2 SO4). This phase also includes the recording of digital images of the final state of the samples, the determination of final density **(γ_f)**, final porosity **(n_f)** and final compressive strength **(σ_f).**

RESULTS AND DISCUSSIONS

After the application of the proposed experimental program on the four stone samples, the following images and results were obtained:

- Digital images were taken of the samples in their fresh state and in their final state. i.e. before and after deterioration due to exposure to 5 cycles of immersion and drying, Immersion for each cycle in acidic water with 5 % concentration of H2SO4 for 72 hours. Drying at 105 ° c for 24 hours.
- Digital images of sectional samples taken from the sample in its final state after calibration according to RGB system. A histogram of the RGB system is shown with the mean color intensity for each of the three standard colors. Sectional here indicates that part of the digital image that contains the points most similar in the degree of change or deterioration of color. It was possible to obtain 25 sectional samples: 10 for sample (L1) and 5 for each of samples (L2; L3 & L4).
- Images of thin sections of samples in their fresh state only. This is because it was not possible to get thin sections from the final deteriorated sample state. The images show mineralogical and textural compositions for studied stone samples as described in the plate caption.
- Table 1 indicates percentages of deterioration of the three standard colors for each sectional sample from which the relationship between mean color intensity and percentage of deterioration for each of the three colors could be obtained as indicated in Figure 1. It also indicates that the percentage of color deterioration varies from one color to another and from one sample to another. However, they all have one common coefficient of correlation (R^2=1) which agrees with the results obtained from the previous phases of the research work.
- Figure 1 and Tables 2 to 4 show that the stages of degree of calculation of deterioration quantitatively is compatible to the results of the previous second phase, i.e. that the samples L1 and L4 have deteriorated more than samples L2 and L3.
- Tables 5 and 6 shows stages in the determination of sample deterioration using acidic water compatible to the environmental conditions to which the monument building stones are exposed and with regard to their physical and mechanical properties as well as the deterioration of the standard three colors. This is done to calibrate the deterioration of color system obtained using digital image processing with deterioration using conventional methods (destructive testing)., This was done to test the validity of the color deterioration system method as a replacement for destructive testing of the monument stone.
- Figures 2 to 6 show the relationships between different deterioration types. It indicates that percentage of color deterioration is very closely related to deterioration of porosity (R^2 = 1), then to deterioration of compressive strength (R^2 = 0.9) then to density (R^2 = 0.8).

CONCLUSIONS

From the results obtained at this stage of our research project it is possible to conclude that the deterioration of colors in weathered rocks is first related to deterioration of porosity, then to deterioration of compressive strength and finally to density deterioration in the stone. This suggests that the use of digital image processing is a valid, non-destructive method, for predicting the durability of stones.

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Table 1. Color deterioration percentage and mean intensity for laboratory tested stone samples

Sample No.	Quarry Name	Section No.	Red Color		Green Color		Blue Color	
			L *	ΔD % **	*L*	ΔD %	*L*	ΔD %
L1	El- Rafaii	L1-1	188	6.0	158	10.2	99	21.4
		L1-2	176	12.0	142	19.3	84	33.3
		L1-3	106	47.0	54	69.3	16	87.3
		L1-4	152	24.0	121	31.3	76	39.7
		L1-5	147	26.5	124	29.5	88	30.2
		L1-6	170	15.0	158	10.2	123	2.3
		L1-7	194	3.0	174	1.1	126	0
		L1-8	150	25.0	102	42.0	48	61.9
		L1-9	179	10.5	150	14.8	99	21.4
		L1-10	152	24.0	115	34.7	65	48.4
L2	Dahshour	L2-1	155	38.7	127	48.0	137	33.5
		L2-2	201	20.6	184	24.6	177	14.1
		L2-3	169	33.2	145	40.6	149	27.7
		L2-4	171	32.4	150	38.5	155	24.8
		L2--5	150	40.7	119	51.2	127	38.3
L3	Helwan	L3-1	216	5.3	222	9.8	190	18.1
		L3-2	211	7.5	218	11.4	189	18.5
		L3-3	219	4.0	231	6.1	201	13.4
		L3-4	187	18.0	195	20.7	172	25.9
		L3-5	199	12.7	205	16.7	178	23.3
L4	Mokattam	L4-1	123	48.4	152	35.4	131	32.1
		L4-2	57	76.3	79	66.4	72	62.7
		L4-3	195	18.8	217	7.7	166	14.0
		L4-4	191	20.4	215	8.5	167	13.5
		L4--5	194	19.2	214	8.9	164	15.0

* L = Mean intensity (from the Histogram of RGB color system) (see plates 2-5)

** ΔD = Deterioration Percentage = (L of reference sample - L of present sample) / (L of reference sample***)

*** RGB of References are as follows:

-For sample L1 = 200 , 176 , 126 , For L2 = 253 , 244 , 206 , For L3 = 228 , 246 , 232 , For L4 = 240 , 235 , 193

Table 2. Total of effected point colors corresponding to the different deterioration categories For studied sections of stone laboratory samples

Sample No.	Deterioration categories*					Total
	Very Low ΔD =(0–20%)	Low (21-40%)	Medium (41-60%)	High (61-80%)	Very High (81-100%)	
L1	12	12	3	2	1	30
L2	1	10	4	-	-	15
L3	12	3	-	-	-	15
L4	9	2	1	3	-	15

* deduced from figures (5- 8)

Table 3. Percentages of deterioration categories in the stone laboratory samples

Sample No.	Percentages of deterioration categories				
	Very Low	Low	Medium	High	Very High
L1	40	40	10	6.7	3.3
L2	6.7	66.6	26.7	-	-
L3	80.0	20.0	-	-	-
L4	60.0	13.3	6.7	20.0	

Table 4. Quantitative situation of the deteriorated stone laboratory samples

Sample No.	Percentages of principal deterioration categories			Description	General classification
	Low & very low	Medium	High & very high		
L1	80	10	10	• many stones in low category • some stones in medium & high categories	**L>H > M**
L2	73.3	26.7	-	• many stones in low category • some stones in medium categories • No stones in high catogory	**L>M–No H**
L3	100	-	-	• All stones in low category • No stones in medium & high categories	**L-No M & H**
L4	73.3	6.7	20.0	• many stones in low category • some stones in high & medium categories	**L > H > M**

Table 5. Comparison between durability results deduced from the digital image processing and from the experimental laboratory work carried out on Egyptian building stones from a selection of ancient historical quarries near Cairo.

Sample No.	Quarry Name	Deterioration of dry density			Deterioration of porosity			Deterioration of strength			(RGB) system**
		γ_i kNlm^3	γ_f kNlm^3	$\Delta\gamma$ %	n_i	n_f	Δn %	σ_{ci} Mpa	σ_{cf} Mpa	$\Delta\sigma$ %	ΔD^* %
L1	El- Rafaii	20.5	19.8	3.5	0.04	0.05	25	35	30	14.3	26.7
L2	Dahshour	19.0	18.0	5.2	0.1	0.14	40	30	20	33	33.8
L3	Helwan	21.5	21.0	2.3	0.1	0.11	10	36	34	5.9	14.1
L4	Mokattam	19.5	17.0	12.8	0.2	0.3	50	15	5	66.7	42.4 **

* D= The average of color deterioration for the three colors (RGB colors) in all studied sectional samples

** corresponding to deteriorated part of sample

Table 6. Summary of physical, mechanical and color deterioration parameters for the laboratory stone samples

Sample No.	$\Delta\gamma$ % (in density)	Δn % (in porosity)	$\Delta\sigma$ % (in strength)	ΔD % (in colors)
L1	3.5	25	14.3	26.7
L2	5.2	40	33	33.8
L3	2.3	10	5.9	14.1
L4	12.8	50	66.7	42.2

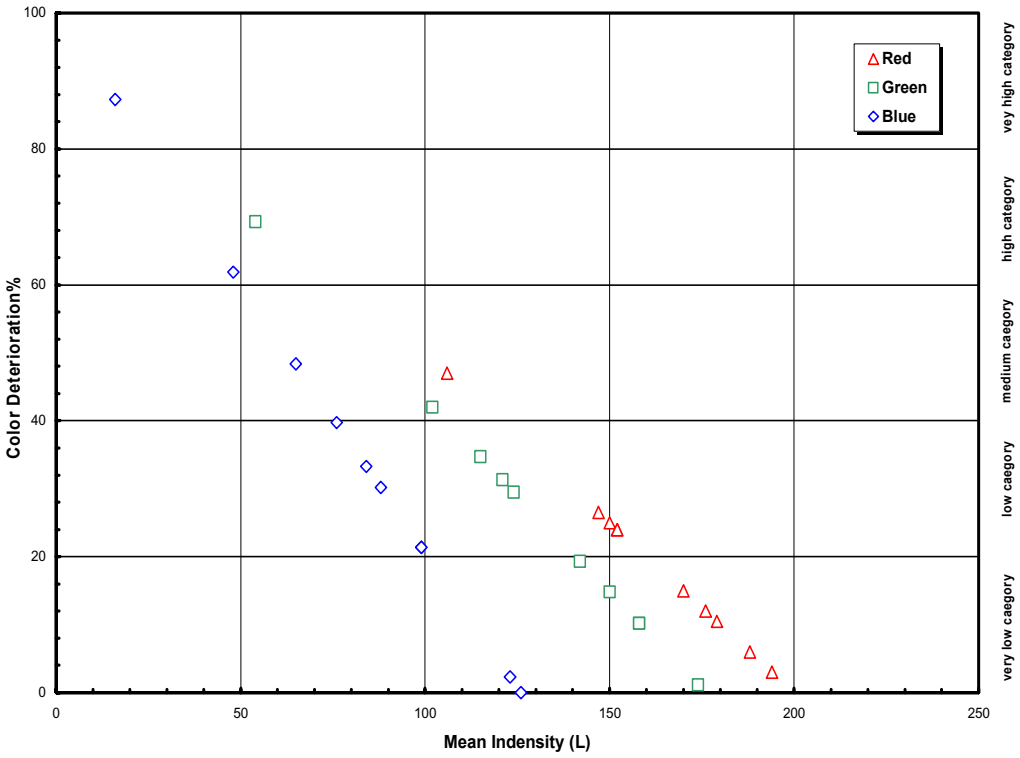

Figure 1. A classified chart to calculate number of all effected colors points for each proposed deterioration category (L1 – Sample)

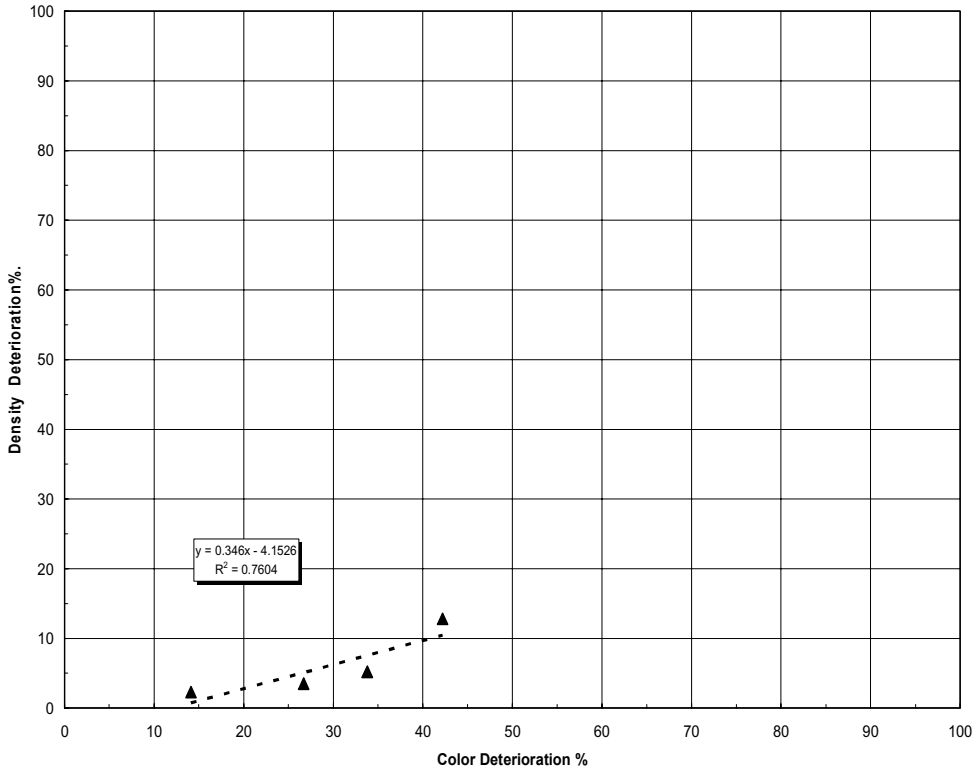

Figure 2. The relationship between color deterioration and density deterioration in the laboratory stone samples

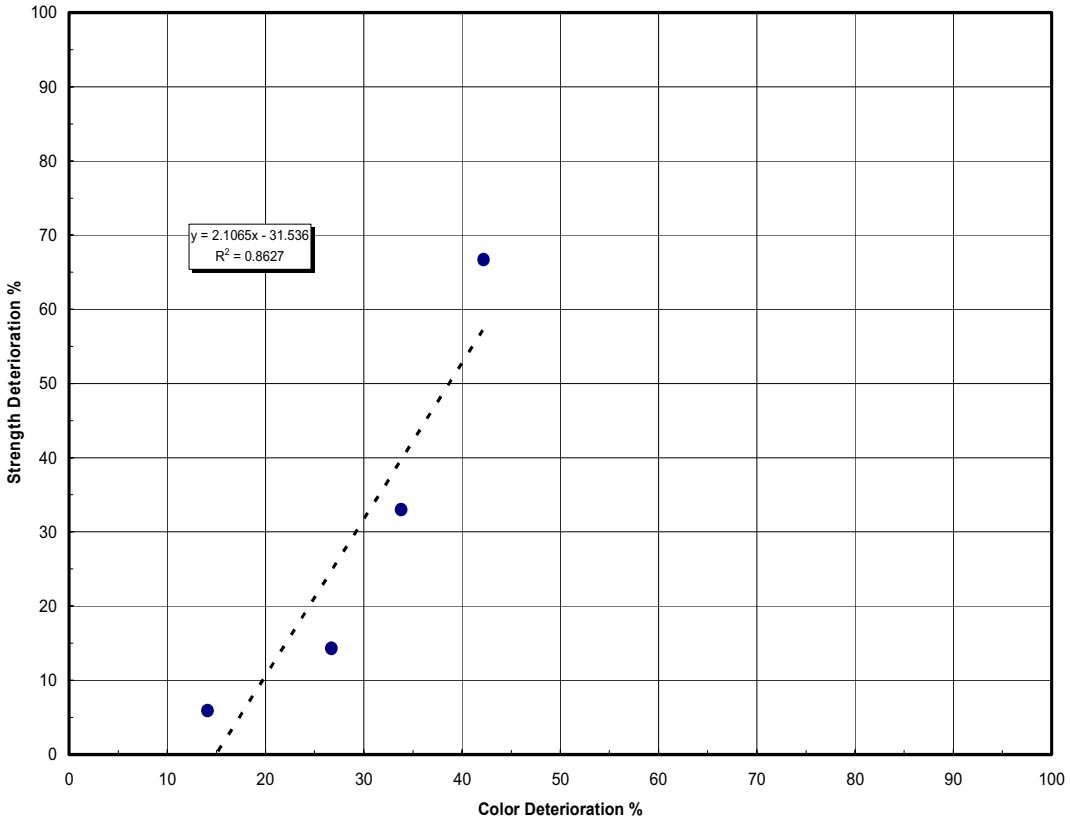

Figure 3. The relationship between color deterioration and strength deterioration in the laboratory stone samples

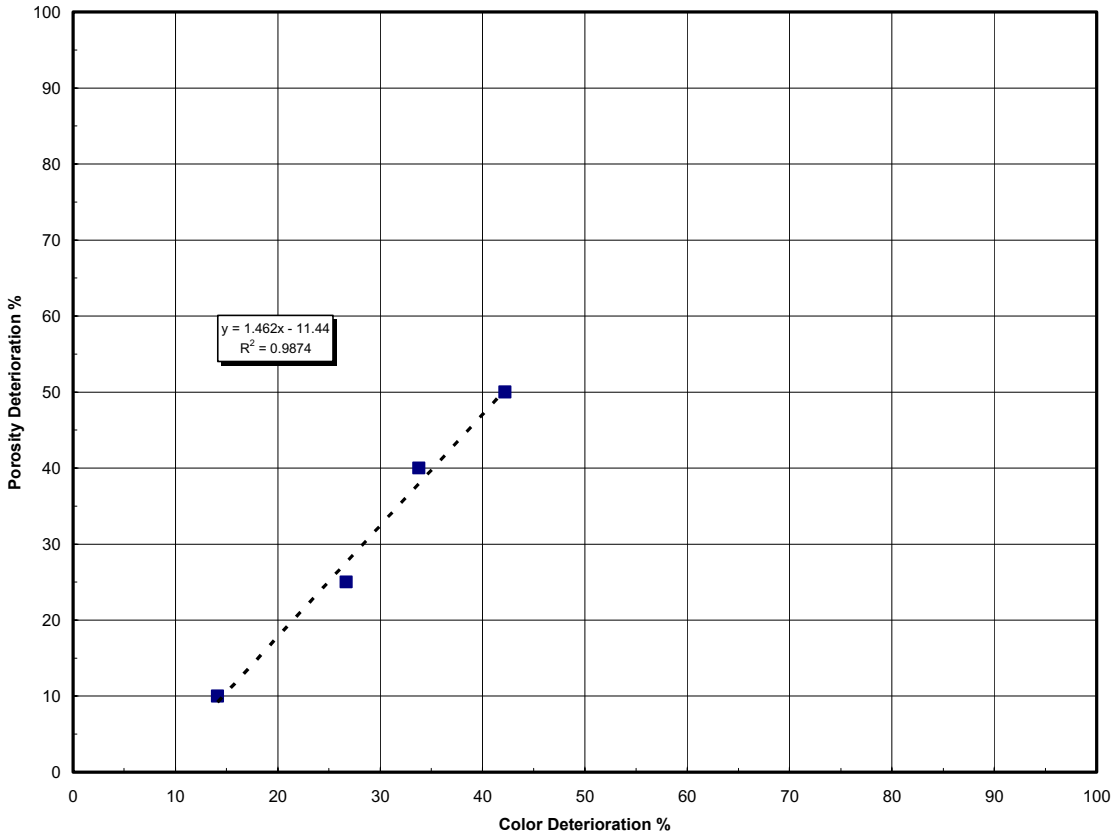

Figure 4. The relationship between color deterioration and porosity deterioration in the laboratory stone samples

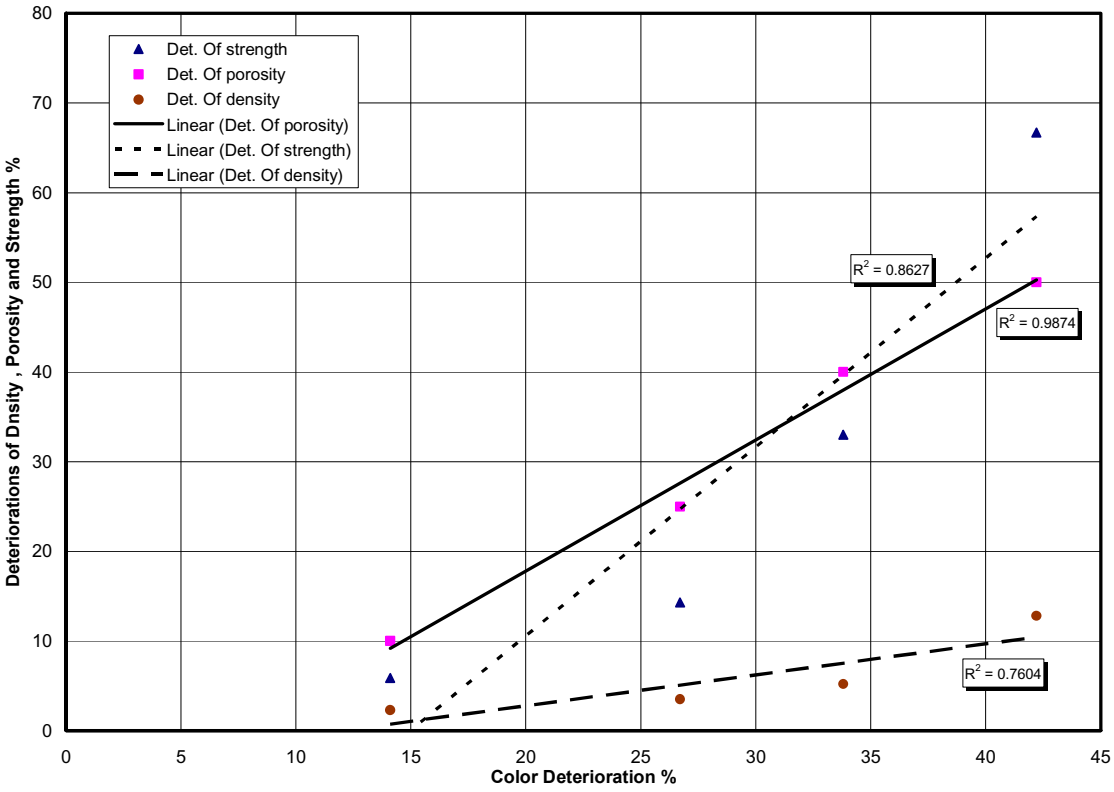

Figure 5. Relationship between color deterioration and the deterioration in density, porosity and strength of the laboratory stone samples

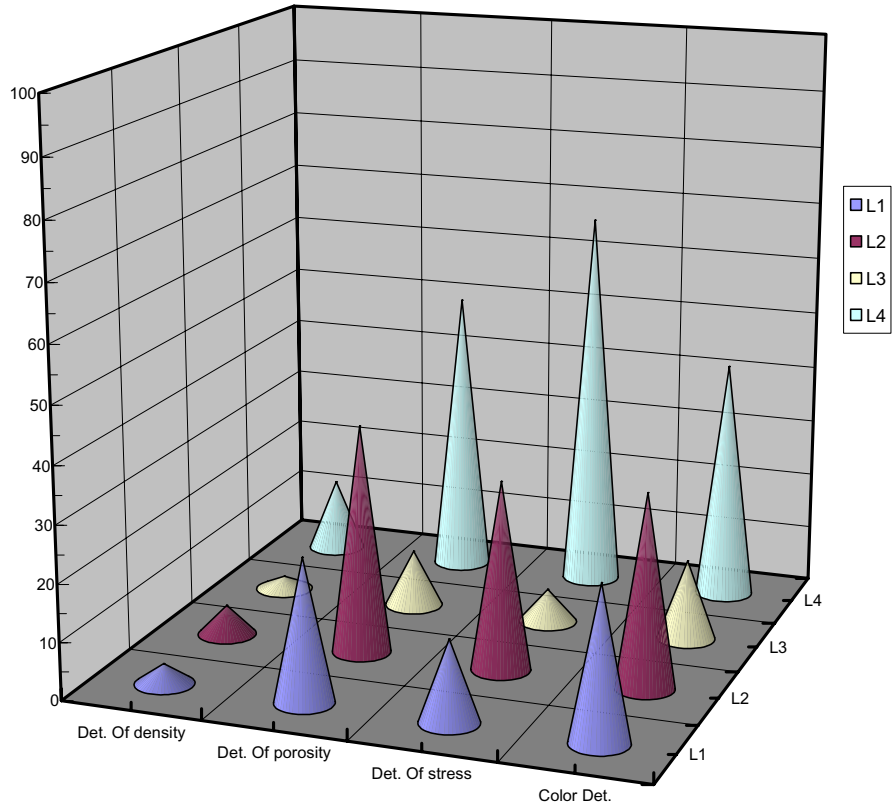

Figure 6. A representative chart showing the variations in deterioration occurring in the studied laboratory stone samples