

Environmental impact on the durability of some Egyptian and Japanese limestones

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**Environmental impact on the durability of
some Egyptian and Japanese limestones**

by

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Synopsis:

Three types of cyclic durability test were done in this study using different wetting liquids during the cycles. These liquids were distilled water, acidic solutions and sodium sulfate solution. The limestone used included 7 samples taken from old and recent constructions in Egypt and 6 samples taken from quarries in Japan. Their basic physical and mechanical properties were determined before and after the test. The trend line of mass-loss percentages by the durability tests was found to be correlated their basic initial properties by the following order: compressive strength, porosity, water absorption and dry density. In addition, it was found that the most simple, fast and representative laboratory test to obtain a good idea about the durability of building limestone -especially for the Egyptian limestone- is the soundness durability test. It has a good and closed relationship with the acidic durability test which is costly and need more time.

Key Words: Limestone, Durability test, Building material

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CONTENTS

1. INTRODUCTION · · · · ·	1
2. DEFINITIONS · · · · ·	2
3. TEST PROGRAM · · · · ·	3
4. RESULTS AND DISCUSSION · · · · ·	5
4.1 Physical and mechanical properties · · · · ·	5
4.2 Mineral compositions · · · · ·	2 2
5. CONCLUSIONS · · · · ·	3 0
REFERENCES · · · · ·	3 1
APPENDIX · · · · ·	3 3

1. INTRODUCTION

The ancient and recent Egyptian and Japanese monuments were almost constructed from the limestone blocs. It is known that limestone's are the most highly soluble rocks to suffer chemical solution (Fookes and Hawkins, 1988). In addition, the polluted atmosphere and rain by acid gases and soot is the main cause of the decay of building limestone. Sulfuric and nitric acids were found to be the dominant components of acid rain (Galloway et al., 1984). However, the acidity of acid rain is principally due to sulfuric acid.

The cycles of these conditions cause formation of a new surface skins of ugly color and tend to exfoliate, blister, decay and structurally damage. These skins consist largely of calcium sulfate, Gypsum mineral that has about five times of its thermal expansion coefficient more than the calcite original mineral. Therefore the surface skin has a greater coefficient of expansion than the stone behind it, and when the temperature changes, the stresses produced by differential expansion will tend to cause lamination of the surface. When the surface of a moist stone becomes warm by exposure to a warm atmosphere, expansion occurs and concurrently, evaporation takes place; crystals of calcium sulfate may thus be deposited in minute cracks produced by the expansion. Continued repetition of this process would tend to produce the observed expansion of the surface layers (Anon, 1989; 1995). However the susceptibility of limestone's to chemical action is a function of assembly many parameters such as: texture, structure, type and percentages of mineral composition, geological origin and presence of porous and fractures. In general, weathering effect increases with the increase of porosity and permeability as well as fineness of grain size. In addition, fluctuations of temperature, moisture and evaporation play their part in promoting the decay of building limestone (Olivier, 1979; Martin and Hencher, 1986; Yatsu, 1988; Brand, 1990; Price, 1995; Vendrell-Saz et al. 1996 and Tanimoto et al. 1997).

Recently, the environmental conditions around building limestones has been remarkably changed especially in Egypt. It changed in most cases due to an acidic conditions caused by extensive industrial plants without any control for atmospheric and water pollution. Also the deteriorations of building limestones for most ancient monuments has become now a very serious problem and it must be note that these stones were stained for long time (about 7,000 years) without any remarkable deteriorations.

In this study we try to evaluate the environmental impact on the behavior of some Egyptian and Japanese building limestone using 5 cycles of wetting/drying durability tests. In addition the basic physical and mechanical properties for the initial intact samples were measured in order to detect a simple, fast and representative laboratory tests to give us some good idea about the durability of building limestones.

2. DEFINITIONS

Two terms from the title of this paper must be defined in advance. The first is durability, and the second is environmental impact.

The durability here means the mass loss percentage of the original sample in terms of certain numbers of wetting/drying cycles exposed to the sample. The environmental impact here means the conditions of wetting and drying during the durability test. By these, two definitions, the natural or artificial environmental conditions existing around the building stones in this laboratory testing program can be represented.

In this study three types of environmental durability tests were done. In the first one, the distilled water was used as a wetting liquid and it is called as distilled water durability test. In the second one, the acidic solution was used as a wetting liquid and it was called acidic solution durability test. In the third one, the sodium sulfate solution was used as a wetting liquid and it was known as the soundness durability test.

3. TEST PROGRAM

The investigated building limestone samples were taken from seven Egyptian building limestone used in the ancient and recent time. They were denoted from sample No. 1 to No. 7. And six Japanese limestones used in general for cement manufacturing and also used for building stones. These were denoted from sample No. 8 to No. 13. The location and geological origin of these samples are shown in Table 1.

Each type of building stone has been cut into four intact samples equal in their weights and their volumes as possible as we could. Their denotation are described as follows:

- 1) Group-1: They are the samples suffixed with-1 (e.g. 1-1; 2-1; 3-1...) and they were specified to the distilled water durability test. The wetting temperature was fixed at 30 °C for 24 hours. The drying temperature was fixed at 105 °C for 23 hours.
- 2) Group-2: They are the samples suffixed with-2 (e.g. 1-2; 2-2; 3-2; ...) and they were specified to the acidic durability test with the same conditions of wetting and drying as group 1.
- 3) Group-3: They are the samples suffixed with-3 (e.g. 1-3; 2-3; 3-3; ...) and they were specified to soundness test. The wetting temperature in this case was fixed at 20 °C for 17 hours and the drying temperature was fixed at 105 °C for 5 hours according to Japanese Industrial Standard (JIS A 1122 "Method of test for soundness of aggregate by use of sodium sulfate").
- 4) Group-4: They are the samples suffixed with-4 (e.g. 1-4; 2-4; 3-4; ...) and they were specified for making thin sections to determine the original textures and mineral compositions.

For the first three groups, the following physical and mechanical properties were measured for the initial and final state:

- 1) Dry weight after drying at 105 °C for 24 hours.
- 2) Water absorption percentage after immersing in distilled water for 96 hours.

Table 1 Locality and geological setting of the studied samples.

Sample Type	Source	Age of Construction	Locality	Geological Setting
1(Egyptian)	Geological bed of Sphinx head	7000 Years.	Giza, Egypt	Upper Eocene
2 (Egyptian)	Geological bed of Sphinx neck	7000 Years.	Giza, Egypt	Upper Eocene
3 (Egyptian)	Old Cairo wall	1000 Years	El- Nasr Door, Cairo	Lower Eocene
4 (Egyptian)	Foundation bed of Al- Azhar mosque	1000 Years	Al- Azhar, Cairo	Upper Eocene
5 (Egyptian)	Tiles of Floor bed of Al-Azhar mosque	1000 Years	Al- Azhar, Cairo	Lower Eocene
6 (Egyptian)	First proposed replacement stone	Not yet	Mokattam, Cairo	Lower Eocene
7 (Egyptian)	Second proposed replacement stone	Not yet	Dahshour, Giza	Pliocene
8 (Japanese)	Tadaka- tsukumi Mine	Not yet	Oita Prefecture	Permian
9 (Japanese)	Torigata- yama Mine	Not yet	Kochi Prefecture	Permian
10(Japanese)	Isa Mine	Not yet	Yamaguchi Prefecture	Carboniferous
11(Japanese)	Hachinohe- lime Mine	Not yet	Aomori Prefecture	Triassic
12(Japanese)	Hidaka Mine	Not yet	Saitama Prefecture	Carboniferous
13(Japanese)	Hatsuru Mine	Not yet	Okinawa Prefecture	Permian

- 3) Dry density and porosity.
- 4) Compressive strength using Shore hardness test (ISRM, 1981).
- 5) Colors according to Munsell system and according to L^* , a^* , b^* color space system.
- 6) Ordinary and focus photographs.

For the first and second groups, it is requisite that the solid/liquid ratio must be fixed for all the used samples and in the same time it has to be sufficient to completely immerse sample with the used liquid. It has been found that this corresponds to 1 g solid with 10 cm³ of liquid. In addition all the containers of samples must be put in a water bath with temperature and shaking control during the required times.

At the end of each cycle the mass loss percentage from the original dry weight were determined. In addition, the total mass loss percentage at the final state were determined and denoted by H1 for total mass loss % of water durability test and H2 for total mass loss % of acidic durability test.

For the third group, each sample has been put in a 0.075 mm sieve cage. All the cage's sample must be completely immersed in a bath of 7.5% of Na₂SO₄ solution at 20 °C for 17 hours and drying at 105 °C for 5 hours. This operation was done for 5 cycles. At the end, the total mass loss percentage from the original dry weight were determined according to ASTM C88-83 (ASTM, 1990b) and denoted by H3.

The remaining materials for each sample type were collected and grind to very fine particles to determine mineral compositions using the X-ray diffractometer (XRD) and chemical compositions using the X-ray fluorescence (XRF) spectrometer.

In addition, the mineralogical composition of the weathered products resulted after the durability test with the acidic water were also determined.

4. RESULTS AND DISCUSSION

The initial and final results of physical and mechanical properties of studied samples are shown in Table 2. However, the initial and final colors of studied samples using Munsell and L*a*b* systems are shown in Table 3. Table 4 shows the mass loss percentages during the distilled and acidic water durability tests. The average initial properties of Egyptian and Japanese building limestone as well as their maximum variation values due to the different durability tests were summarized in Table 5.

From all these tables the behaviors of studied samples in function of different durability tests are analyzed in the following steps.

4.1 Physical and mechanical properties

Variation of physical and mechanical properties before and after the different durability tests is observed by Figures 1 to 3. The total mass loss percentages of original samples for the different durability tests are shown in Figure 4. From all these figures, it can be seen that the acidic durability test is the most effective durability test on the physical and mechanical properties. On the other side, the effect of the distilled water durability test is very low. The degree of effect of soundness durability test was considered as of medium degree but it is nearer to the acidic test than to the distilled water. All these observations are summarized in Table 5.

The mass loss percentages during and after cycles for distilled and acidic water durability tests are constructed in Figures 5 to 8. From these figures, it was observed that there was some effect during the second and fourth cycles of distilled water. But during the first, third and fifth cycles the effect was a little bit more. This mean that the rate of weathering affected by the distilled water durability test was very slow with a little quantity mass loss. On the other side, higher effective rate during acidic durability test was remarkable during all the cycles.

Trend lines of the total mass loss percentages after different durability tests in function of the basic initial properties are traced in Figures 9 to 12. From these figures, it could be concluded that the trend lines of the mass loss percentages obtained from acidic and soundness durability tests are close. Their trend was correlated with the basic initial properties in the following order: compressive strength, porosity, water absorption and dry density.

Relationship between total mass loss percentages resulting from the different types of

Table 2 Intial and final physical and mechanical properties of the studied samples.

Sample Type	Sample No.	Initial Physical & Mechanical Properties					Final Physical & Mechanical Properties after 5 Cycles of Durability Tests							
		Dry Weight (g)	Dry Density (t/m3)	Water Absorption (%)	Porosity	Compressive Strength (Mpa)	Dry Weight (g)	Dry Density (g/cm3)	Water Absorption (%)	Porosity	Compressive Strength (Mpa)	Total Mass Loss Percentages		
												distilled water H1(%)	acidic water H2(%)	soundness tests H3 (%)
1(Egyptian)	1-1	31.22	2.31	4.74	0.11	39.9	31.01	2.25	4.98	0.11	37.8	0.67		
	1-2	28.14	2.33	4.44	0.1	39.9	28.08	1.90	6.80	0.13	29.4		7.32	
	1-3	33.63	2.27	5.65	0.13	35.7	25.87	2.26	6.44	0.15	31.5			23.07
2 (Egyptian)	2-1	7.68	1.79	17.45	0.31	12.6	7.6	1.75	16.42	0.29	12.6	1.04		
	2-2	11.42	1.8	16.64	0.3	14.7	0						100	
	2-3	10.04	1.83	15.74	0.29	16.8	0							100
3 (Egyptian)	3-1	18.13	2.14	7.4	0.16	42	18.01	2.12	7	0.15	37.8	0.66		
	3-2	16.04	2.15	7.36	0.16	39.9	14.6	2.1	9.46	0.2	35.7		8.98	
	3-3	21.38	2.1	9.78	0.2	39.9	18.4	2.1	9.9	0.21	33.6			13.94
4 (Egyptian)	4-1	10.63	1.99	10.44	0.21	16.8	10.6	1.99	10.28	0.2	14.7	0.18		
	4-2	14.31	1.94	11.25	0.22	18.9	5.7	1.62	21.58	0.35	0		60.17	
	4-3	7.8	2.03	9.87	0.2	16.8	3.28	1.99	10.3	0.34	0			57.95
5 (Egyptian)	5-1	14.16	1.73	18.36	0.32	25.2	14	1.72	13.88	0.2	23.1	1.13		
	5-2	17.45	1.72	18.51	0.32	23.1	15.3	1.65	17.94	0.3	16.8		12.32	
	5-3	18.63	1.76	15.83	0.28	23.1	18.4	1.75	15.9	0.28	21			1.26
6 (Egyptian)	6-1	29.96	2.02	2.6	0.05	44.1	29.8	2.02	1.61	0.03	44.1	0.53		
	6-2	29.04	2.04	2.54	0.05	42	26	2	2.91	0.06	37.8		10.47	
	6-3	32.54	2	3.72	0.07	42	32.11	2	7.13	0.14	39.9			1.26
7 (Egyptian)	7-1	23	2.02	4.3	0.09	31.5	22.96	2.02	3.35	0.07	29.4	0.17		
	7-2	19.73	1.93	4.66	0.09	33.6	17.62	1.85	10.38	0.2	27.3		10.69	
	7-3	18.18	1.9	4.99	0.09	33.6	12.6	1.89	7.94	0.15	25.2			30.69
8 (Japanese)	8-1	14.04	2.7	0.21	0.006	136	14.02	2.7	0.29	0.008	136	0.14		
	8-2	14.96	2.7	0.22	0.007	129.2	14	2.64	1.43	0.04	122.4		6.42	
	8-3	11.3	2.71	0.2	0.005	132.6	11.26	2.68	0.4	0.01	132			0.35
9 (Japanese)	9-1	13.06	2.69	0.33	0.006	125.8	13.03	2.69	0.36	0.01	125.6	0.23		
	9-2	5.74	2.69	0.34	0.008	122.4	5.23	2.55	2.29	0.06	115.6		8.89	
	9-3	8.25	2.7	0.3	0.01	125.8	8.22	2.69	0.43	0.01	122.4			0.36
10(Japanese)	10-1	16.27	2.7	0.3	0.008	119	16.23	2.7	0.37	0.009	119	0.25		
	10-2	5.03	2.65	0.4	0.01	122.4	4.55	2.54	2.2	0.06	112.2		9.54	
	10-3	8.99	2.65	0.44	0.01	122.4	8.97	2.65	0.52	0.01	119			0.22
11(Japanese)	11-1	9.24	2.69	0.32	0.009	122.4	9.22	2.69	0.43	0.01	122.1	0.43		
	11-2	6.83	2.68	0.33	0.008	119	6.26	2.59	1.92	0.05	112.2		8.35	
	11-3	4.2	2.66	0.36	0.006	119	4.18	2.66	0.5	0.01	112.4			0.48
12(Japanese)	12-1	7.59	2.7	0.26	0.007	112.2	7.57	2.7	0.40	0.01	112	0.26		
	12-2	7.1	2.68	0.3	0.008	115.6	6.36	2.6	1.57	0.04	105.4		10.42	
	12-3	6.95	2.68	0.3	0.008	108.8	6.91	2.69	0.5	0.008	105.4			0.58
13(Japanese)	13-1	11.77	2.68	0.35	0.007	139.4	11.75	2.68	0.43	0.01	139.2	0.17		
	13-2	10.09	2.71	0.3	0.008	146.2	9.12	2.6	1.10	0.02	139.4		9.61	
	13-3	6.62	2.72	0.2	0.008	132.6	6.61	2.72	0.4	0.01	129.2			0.15

*Samples No. with- 1 specified for durability test with distilled water and with- 2 specified for durability test with acidic water (1N H₂SO₄) and with- 3 specified for durability soundness test with (7.5% Na₂SO₄)

** Compressive strength determined by Shore hardness rebound using the lower limit equation for the Egyptian samples (compressive strength in Mpa = 2.1 Hs, where Hs is the rebound of Shore hardness) and the upper limit equation for the Japanese samples (compressive strength in Mpa = 3.4 Hs) (after Wuerker, 1953)

Table 3 Intial and final colors of the studied samples.

Sample Type	Sample No.	Initial Average Colors									Final Average Colors								
		Intact Samples						Powder Samples			Intact Samples						Weathered Powder After Durability Acidic test		
		Munsell System			L*a*b Color Space System			Munsell System			Munsell System			L*a*b Color Space System			Munsell System		
			L*	a*	b*			L*	a*	b*		L*	a*	b*			L*	a*	b*
1(Egyptian)	1-1	10YR- 8/2	76.6	+3.3	+14.5						7.5YR-8/2	81.0	+3.5	+9.3					
	1-2	10YR- 7/3	77.9	+2.9	+12.0						N-8/0	72.4	+1.1	+3.0	10YR-5/1	53.8	+3.4	+7.0	
	1-3	10YR- 8/3	65.8	+6.3	+21.4						7.5YR-8/1	76.2	+2.8	+10.5					
2 (Egyptian)	2-1	10YR- 8/4	73.0	+7.9	+27.5						7.5YR-8/3	79.5	+5.4	+13.3					
	2-2	10YR- 7/4	71.3	+8.8	+28.9						N-7/1	70.0	+1.5	+3.5	10YR-6/2	60.0	+3.9	+10.8	
	2-3	10YR- 8/4	72.2	+7.7	+26.6						7.5YR-8/3	79.0	+6.5	+15.9					
3 (Egyptian)	3-1	10YR- 7/2	79.0	+2.5	+10.4						7.5YR-8/2	84.0	+1.4	+5.9					
	3-2	10YR- 8/2	78.8	+2.8	+11.5						5YR-8/1	74.9	+2.2	+7.0	7.5YR-3/1	31.2	+3.8	+5.8	
	3-3	10YR- 8/2	72.6	+4.4	+15.3						5YR-8/3	81.4	+1.3	+7.4					
4 (Egyptian)	4-1	10YR- 7/4	75.2	+7.1	+22.9						7.5YR-8/2	80.7	+4.8	+11.9					
	4-2	10YR- 6/4	72.1	+8.5	+24.3						N-8/0	70.7	+1.7	+3.9	10YR-7/2	68.9	+3.3	+9.9	
	4-3	7.5YR- 6/4	63.1	+10.5	+26.9						2.5YR-7/2	71.5	+4.5	+10.8					
5 (Egyptian)	5-1	10YR- 8/3	79.8	+3.3	+13.4						7.5YR-8/2	83.3	+2.9	+9.3					
	5-2	10YR- 8/2	80.5	+3.1	+14.4						N-8/0	71.3	+2.5	+4.9	7.5YR-6/1	60.8	+2.9	+6.0	
	5-3	10YR- 8/2	75.1	+4.5	+16.2						5YR-8/2	77.0	+3.1	+11.3					
6 (Egyptian)	6-1	10YR- 7/3	75.4	+4.0	+15.2						5YR-8/2	83.2	+2.7	+8.2					
	6-2	7.5YR- 8/2	75.0	+4.3	+15.8						N-7/0	74.6	+0.8	+3.4	7.5YR-5/1	50.9	+2.0	+3.7	
	6-3	10YR- 8/2	79.8	+3.2	+13.0						7.5YR-8/1	81.1	+1.9	+10.4					
7 (Egyptian)	7-1	10YR- 7/3	69.8	+6.5	+16.8						5YR-8/2	78.2	+4.3	+8.6					
	7-2	7.5YR- 7/4	60.0	+10.4	+24.3						5RP-7/1	63.1	+1.6	+1.9	7.5YR-3/1	26.5	+2.2	+2.9	
	7-3	7.5YR- 7/4	68.2	+7.5	+20.7						5YR-8/1	75.5	+3.6	+10.4					
8 (Japanese)	8-1	N-7/0	67.1	-0.2	0.0						N-8/0	74.8	-0.5	-0.9					
	8-2	N-7/0	63.4	-0.2	-0.6						5P-7/1	69.8	-0.9	-1.3	N-7/0	60.6	+1.3	+2.8	
	8-3	N-7/0	65.1	-0.2	-0.9						N-8/0	70.4	-1.2	-1.1					
9 (Japanese)	9-1	N-8/0	78.9	+0.2	+0.3						N-8/0	82.0	0.0	0.0					
	9-2	N-8/0	74.9	+0.9	+2.2						5P-7/1	74.0	+0.3	+2.3	7.5YR-6/1	47.5	+0.8	+0.8	
	9-3	N-8/0	73.3	+1.4	+4.9						N-8/0	76.7	-0.4	+2.4					
10(Japanese)	10-1	N-8/1	82.2	+0.7	+1.2						N-8/0	84.6	+0.2	+1.6					
	10-2	N-8/1	70.5	+2.1	+5.5						5P-7/1	74.6	+0.5	+3.8	N-6/0	49.5	+0.8	+0.5	
	10-3	N-8/1	78.0	+0.7	-0.3						N-8/0	83.1	-0.7	+0.6					
11(Japanese)	11-1	N-6/0	56.6	-0.2	-2.2						N-5/0	71.0	-0.6	-2.8					
	11-2	N-6/0	59.7	0.0	-1.2						5P-7/1	60.4	-1.0	-2.7	N-6/0	55.5	+1.0	+1.9	
	11-3	N-6/0	60.0	-0.1	-1.9						N-6/0	72.9	-1.3	-1.2					
12(Japanese)	12-1	N-7/0	67.9	+0.3	+0.8						N-8/0	74.9	+0.1	-0.6					
	12-2	N-7/0	45.3	+0.1	-0.7						5P-7/1	73.0	-1.3	-2.0	7.5R-5/1	54.3	+1.6	+2.9	
	12-3	N-7/0	69.5	-0.6	-0.7						N-8/0	76.7	-1.4	-0.6					
13(Japanese)	13-1	N-5/0	58.8	+0.4	+1.3						N-4/0	72.6	0.0	-0.8					
	13-2	N-5/0	49.4	+1.2	+4.4						5P-7/1	66.6	-0.3	-0.3	5YR-6/1	63.4	+1.9	+4.2	
	13-3	N-5/0	49.8	+0.1	+0.5						N-4/0	67.4	-0.7	-1.4					

Table 4 Mass loss percentages during the durability tests with distilled water and acidic solution.

Sample Type	Sample No.	Mass Loss Percentages During Durability Test Cycles with Distilled Water						Sample No.	Mass Loss Percentages During Durability Test Cycles with Acidic Water (1N H ₂ SO ₄)					
		1st cycle	2nd cycle	3rd cycle	4th cycle	5th cycle	Total		1st cycle	2nd cycle	3rd cycle	4th cycle	5th cycle	Total
1(Egyptian)	1-1	0.38	0	0.13	0	0.16	0.67	1-2	1.81	0.82	2.17	0.78	1.74	7.32
2(Egyptian)	2-1	0.13	0	0.39	0.26	0.26	1.04	2-2	38	47.37	14.63			100
3(Egyptian)	3-1	0.28	0	0.1	0	0.28	0.66	3-2	1.5	1.18	2.24	0.56	3.5	8.98
4(Egyptian)	4-1	0.09	0	0.09	0	0	0.18	4-2	12.16	12.58	13.49	10.48	11.46	60.17
5(Egyptian)	5-1	0.64	0	0.14	0.07	0.28	1.13	5-2	2.58	0.97	4.36	0.86	3.55	12.32
6(Egyptian)	6-1	0.13	0	0.17	0	0.23	0.53	6-2	2.68	1.14	2.57	1.08	3	10.47
7(Egyptian)	7-1	0.09	0	0.08	0	0	0.17	7-2	2.23	0.96	2.58	1.02	3.9	10.69
8(Japanese)	8-1	0	0	0.14	0	0	0.14	8-2	1.34	0.87	1.94	0.6	1.67	6.42
9(Japanese)	9-1	0	0	0.08	0	0.15	0.23	9-2	1.39	1.22	2.61	1.57	2.1	8.89
10(Japanese)	10-1	0	0.07	0	0	0.18	0.25	10-2	1.59	1.39	2.58	1	2.98	9.54
11(Japanese)	11-1	0.1	0.11	0	0	0.22	0.43	11-2	1.61	1.32	2.34	1.03	2.05	8.35
12(Japanese)	12-1	0.13	0	0.13	0	0	0.26	12-2	1.56	1.69	2.25	2.39	2.53	10.42
13(Japanese)	13-1	0	0	0	0	0.17	0.17	13-2	1.39	1.68	2.97	1.49	2.08	9.61

Table 5 Summary of the average initial properties and its maximum variations of Egyptian and Japanese limestones before and after different durability tests.

Test Type	Egyptian Limestone					Japanese Limestone				
	Dry Density ton/m ³	Water Absorption (%)	Porosity	Compressive Strengt (Mpa)	Total Mass Loss H (%)	Dry Density ton/m ³	Water Absorption (%)	Porosity	Compressive Strengt (Mpa)	Total Mass Loss H (%)
average values in the initial State	1.99	9.35	0.18	30.1	—	2.69	0.3	0.008	125.4	—
Variation due to Water Durability (H1)	- 0.06	- 4.48	- 0.12	- 4.2	+ 1.13	0.0	+ 0.14	+ 0.004	- 0.3	+ 0.43
Variation due to Acidic Durability (H2)	- 0.43	+ 10.38	+ 0.11	- 18.9	+ 100	- 0.11	+ 2.29	+ 0.05	- 10.2	+ 10.42
Variation due to Soundness Durability (H3)	- 0.04	+ 3.41	+ 0.14	- 16.8	+ 100	- 0.03	+ 0.21	+ 0.005	- 6.6	+ 0.56

Figure 1 Variations of physical and mechanical properties of studied samples before and after distilled water durability test.

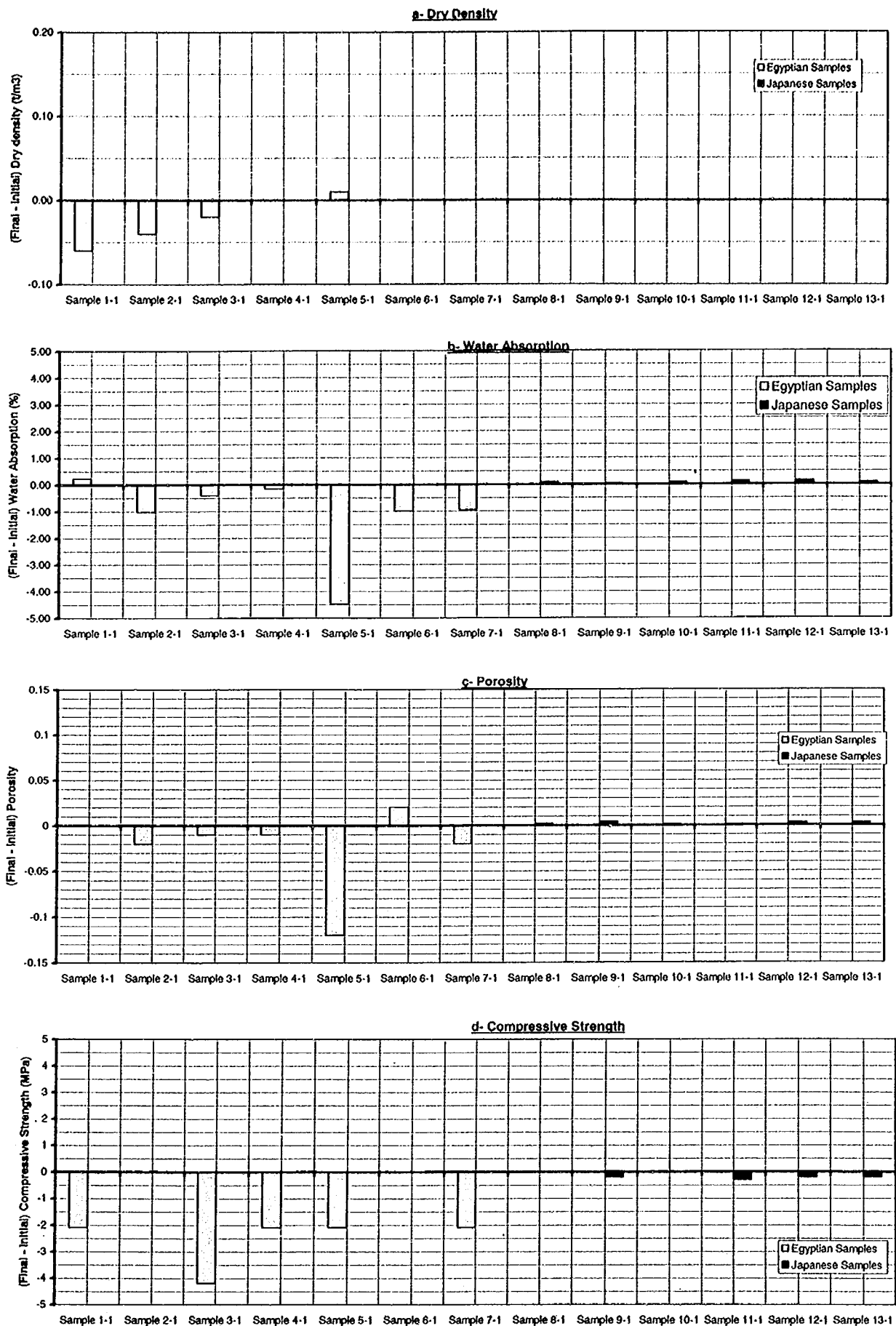


Figure 2 Variations of physical and mechanical properties of studied samples before and after acidic solution durability test.

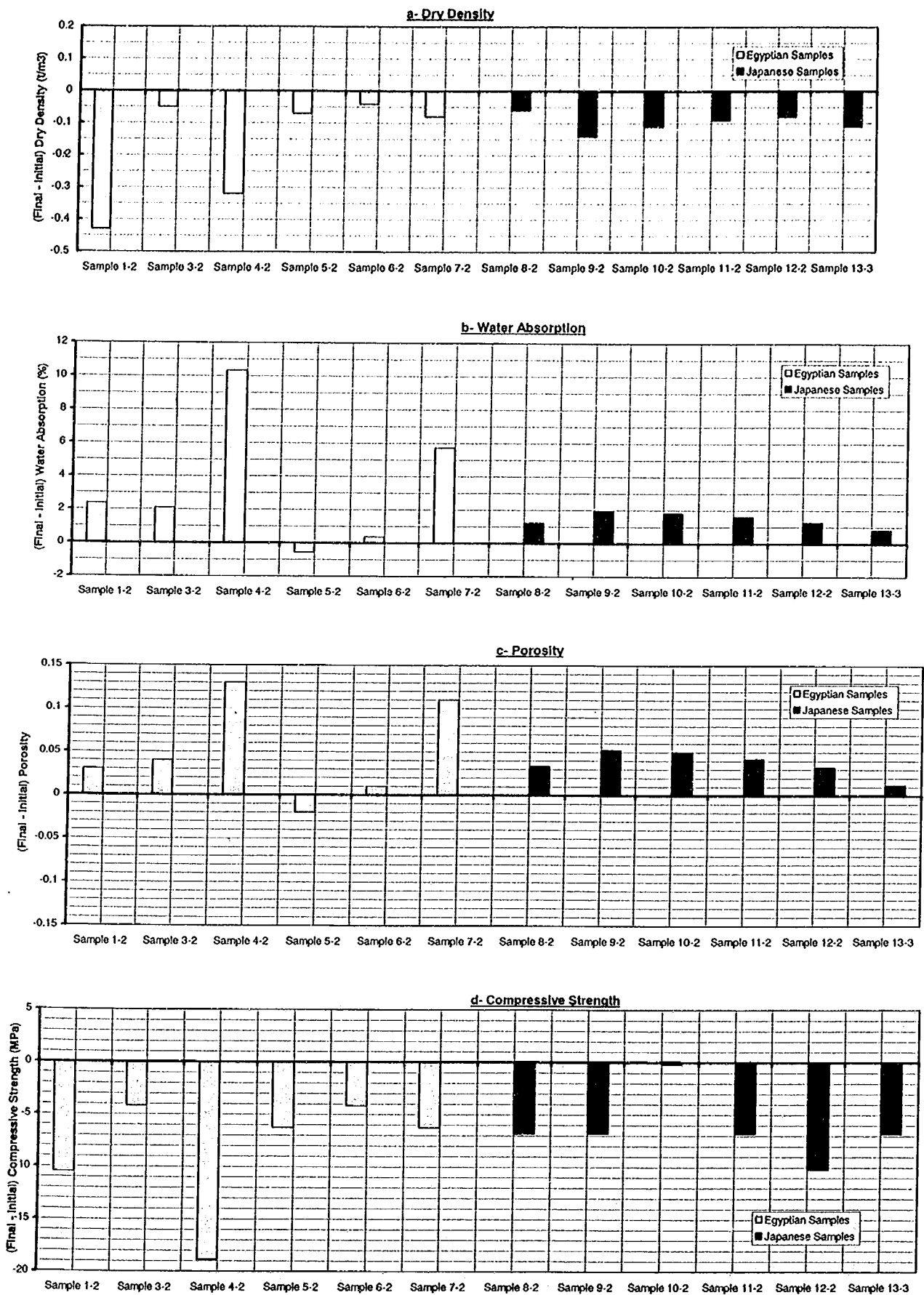


Figure 3 Variations of physical and mechanical properties of studied samples before and after soundness durability test.

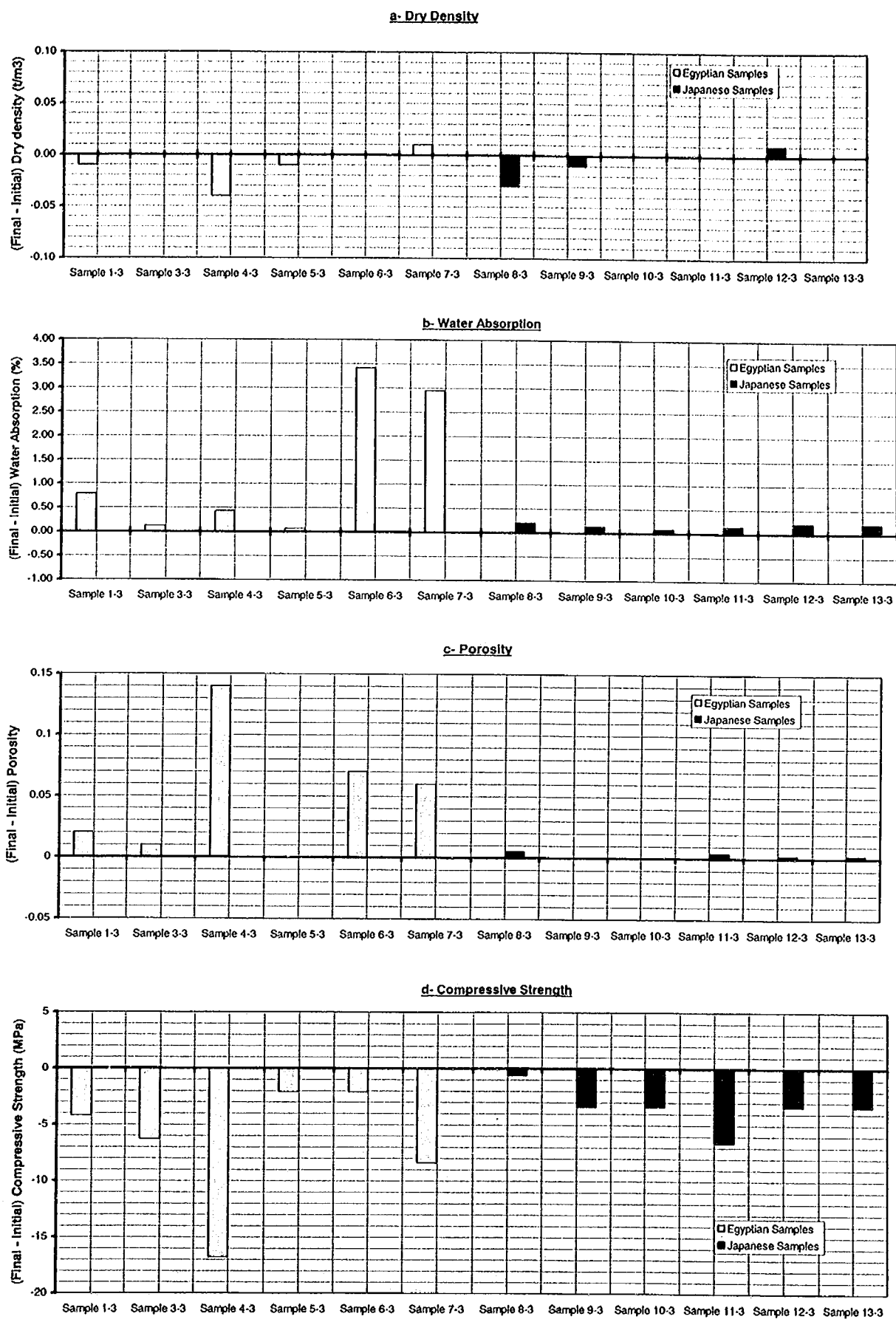


Figure 4 Mass loss percentages of studied samples after different durability tests.

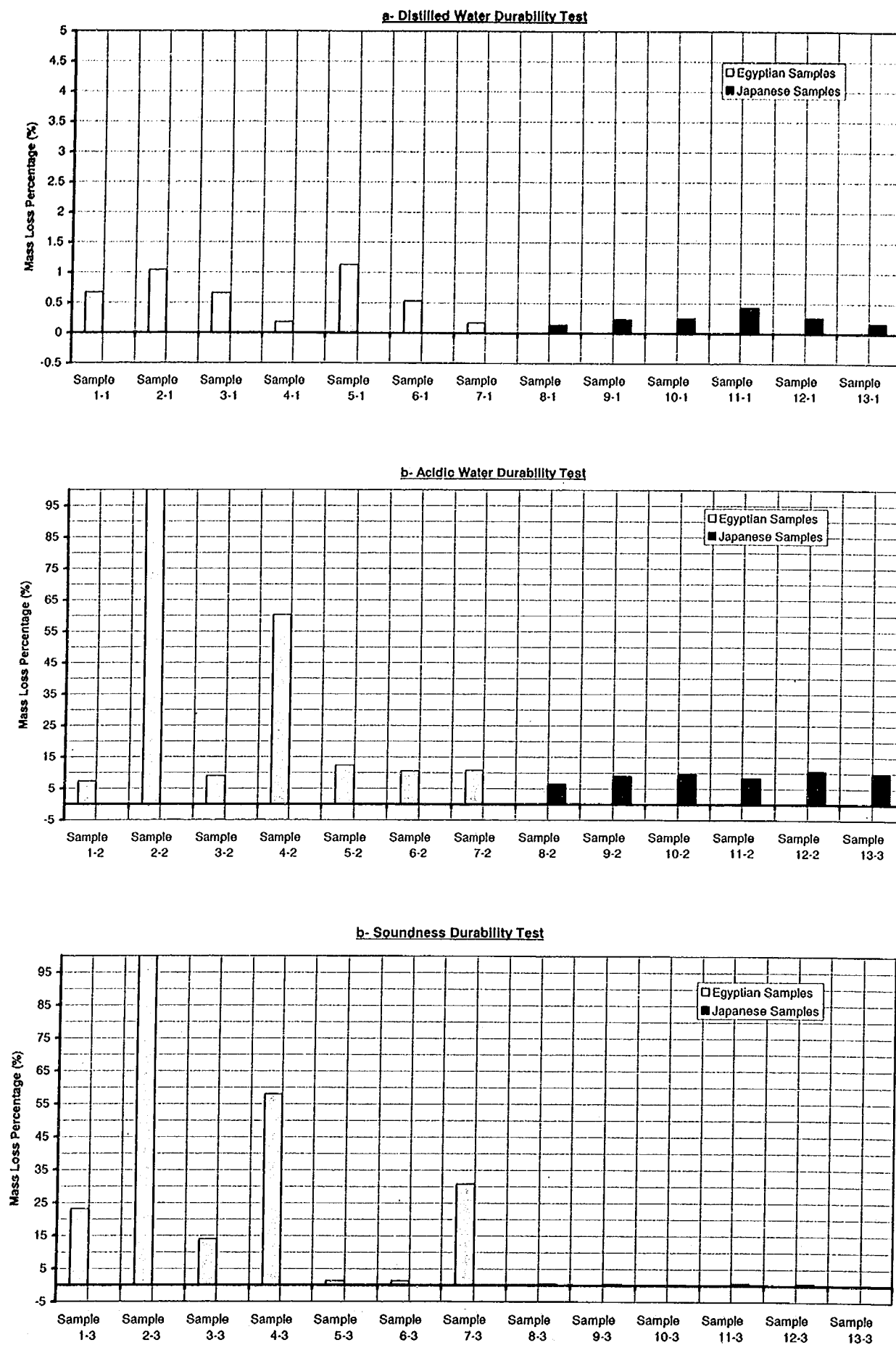
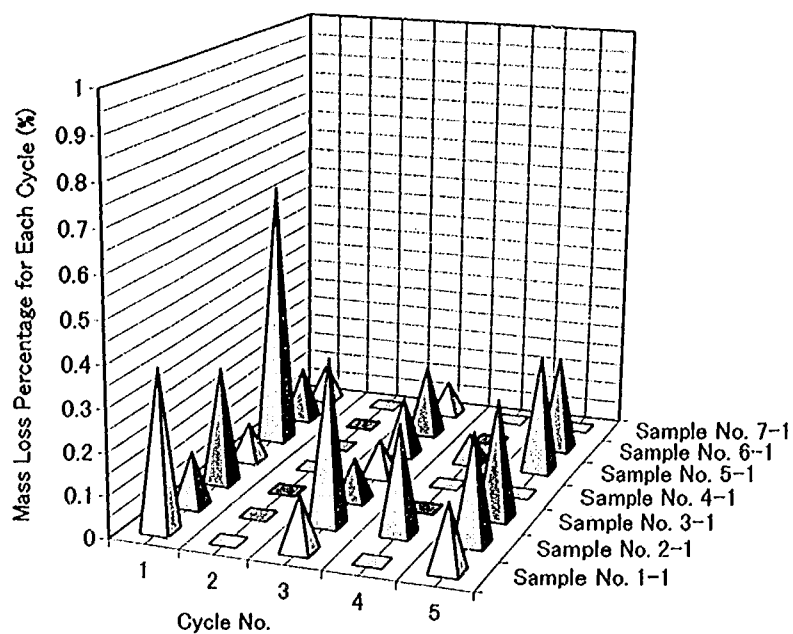


Figure 5 Mass loss percentages of studied samples during cycles of distilled water durability test.

a- Egyptian Samples



b- Japanese Samples

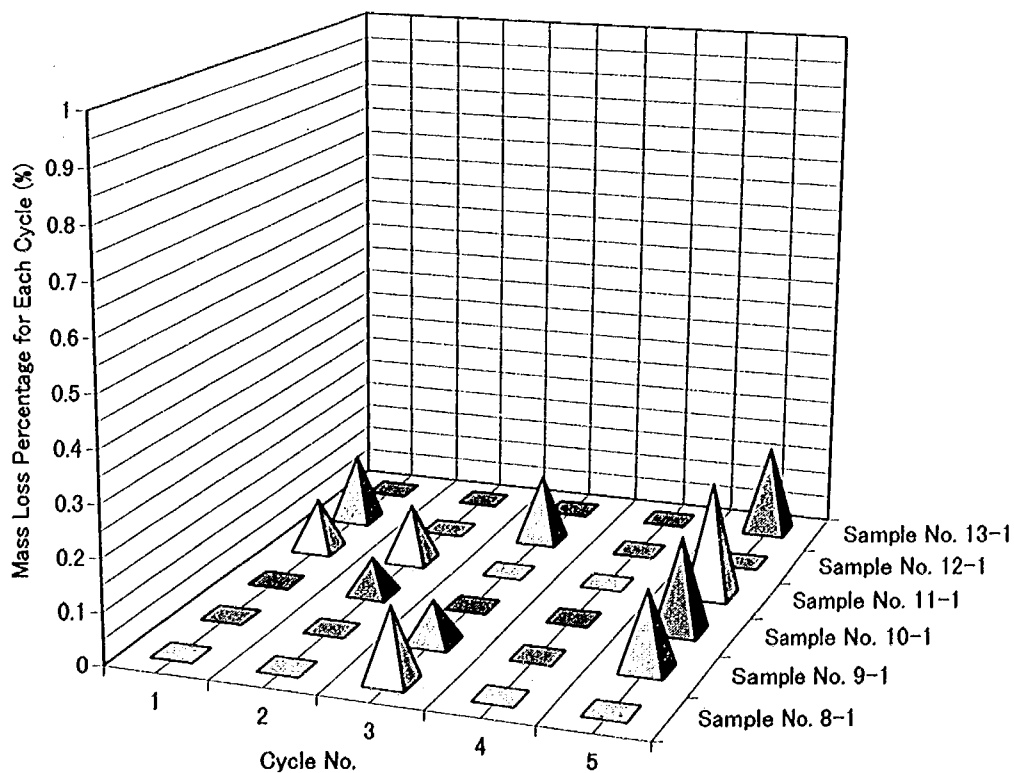
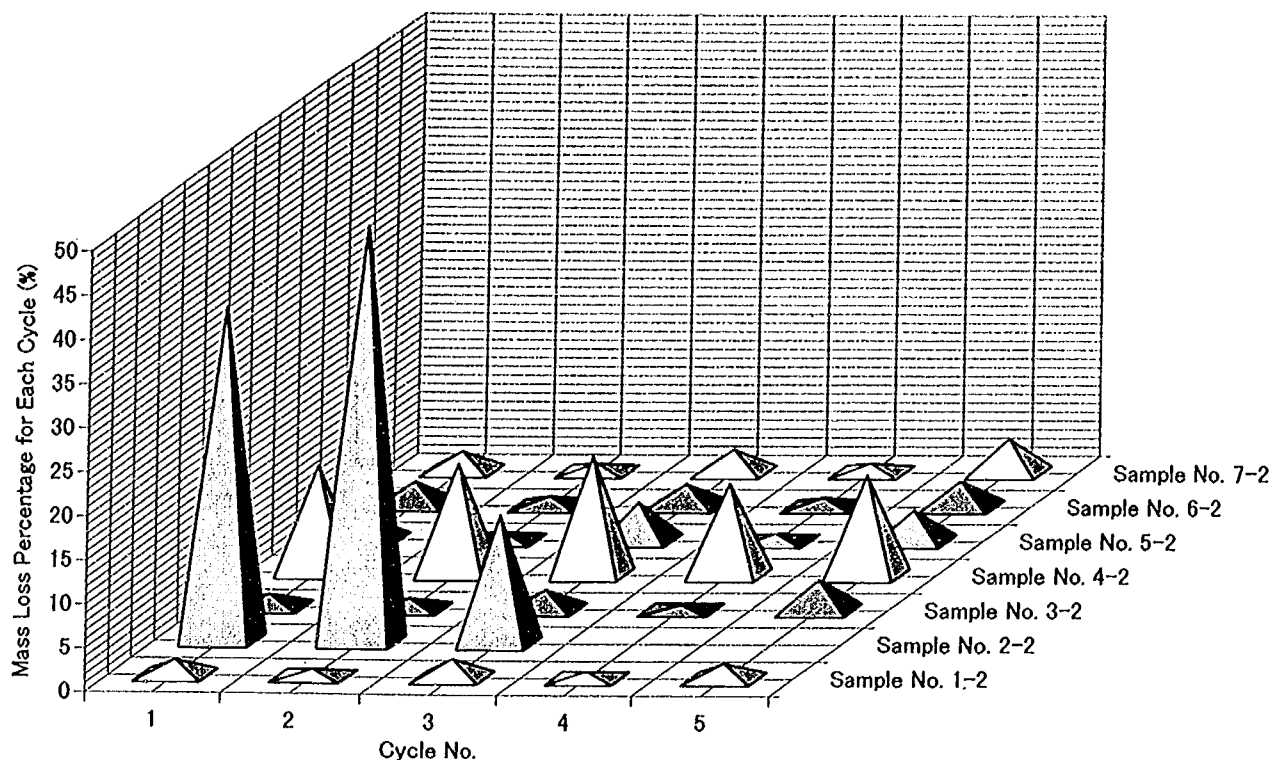


Figure 6 Mass loss percentages of studied samples during cycles of acidic solution durability test.

a- Egyptian Samples



b- Japanese Samples

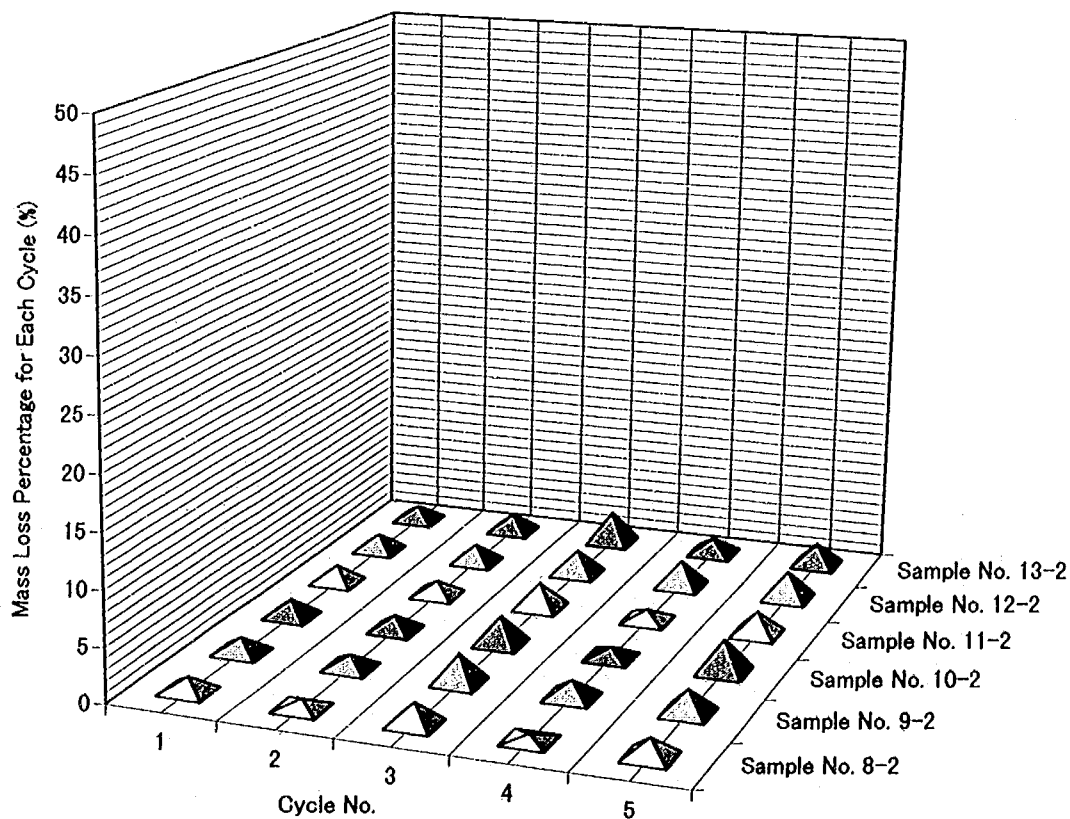
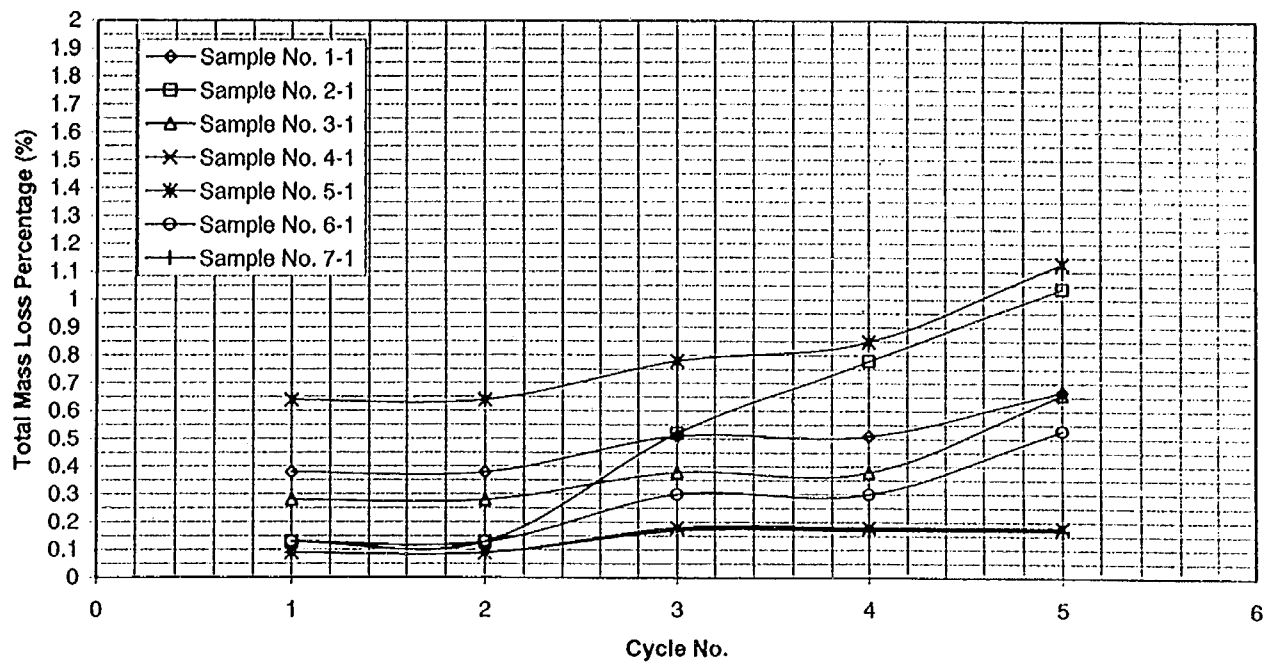


Figure 7 Total mass loss percentages of studied samples after 5 cycles of distilled water durability test.

a- Egyptian samples



b- Japanese Samples

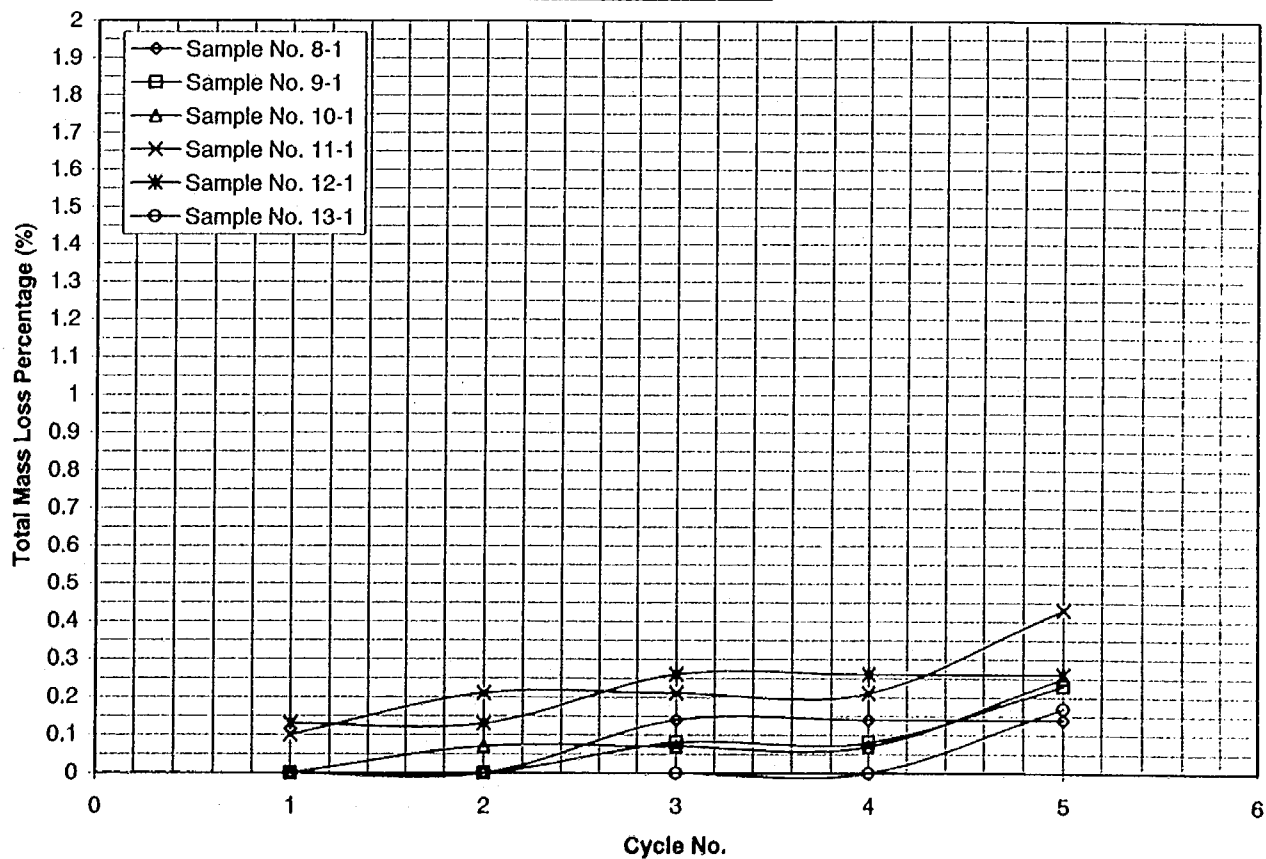
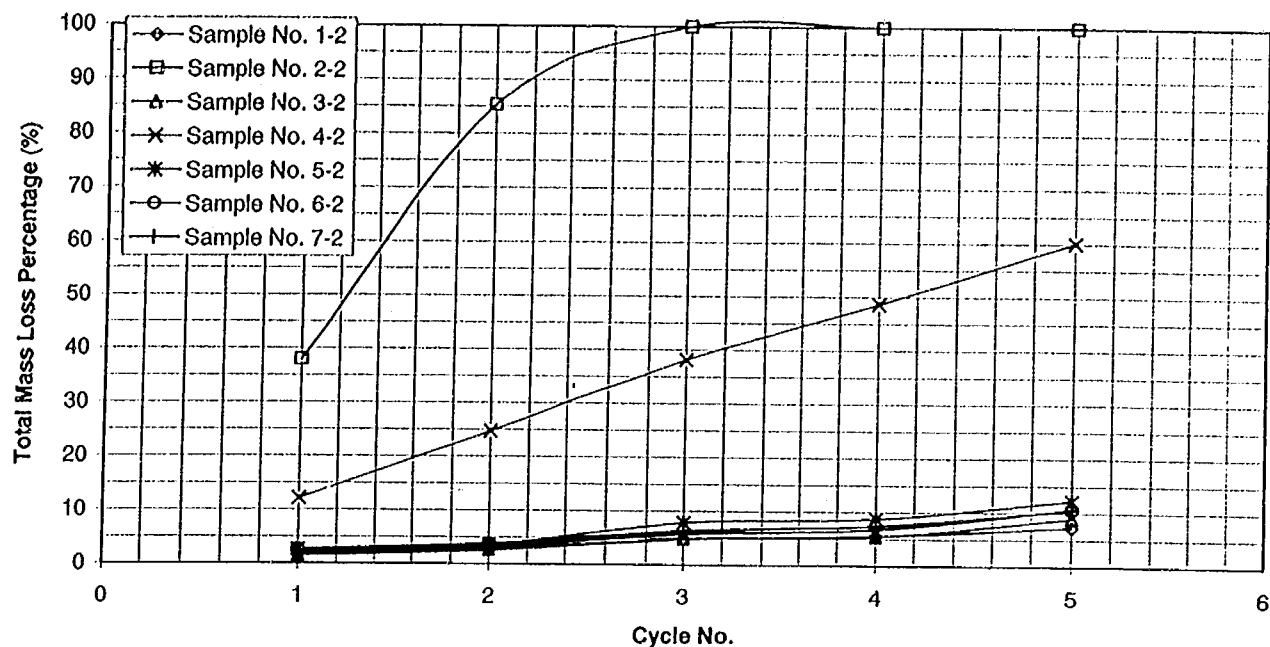


Figure 8 Total mass loss percentages of studied samples after 5 cycles of acidic solution durability test.

a- Egyptian samples



b- Japanese Samples

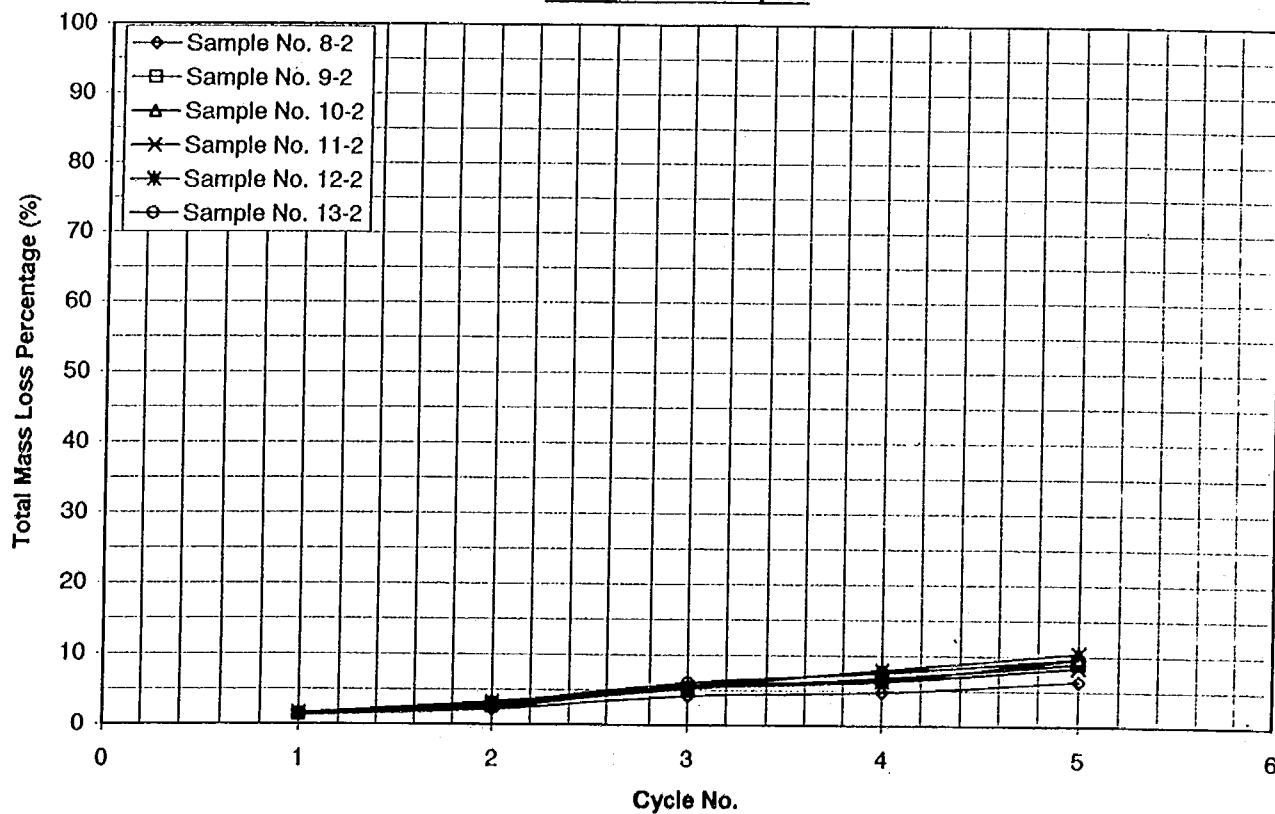
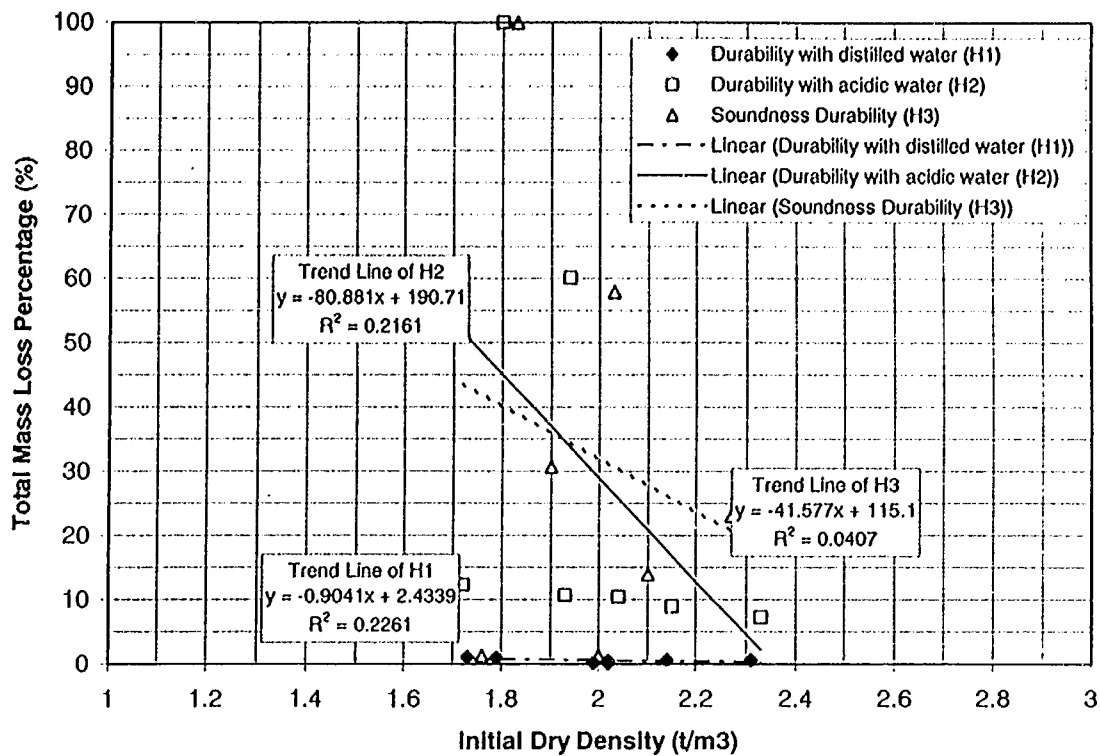


Figure 9 Trend lines of total mass loss percentages of studied samples after different durability tests in function of initial dry density.

a- Egyptian Samples



b- Japanese Samples

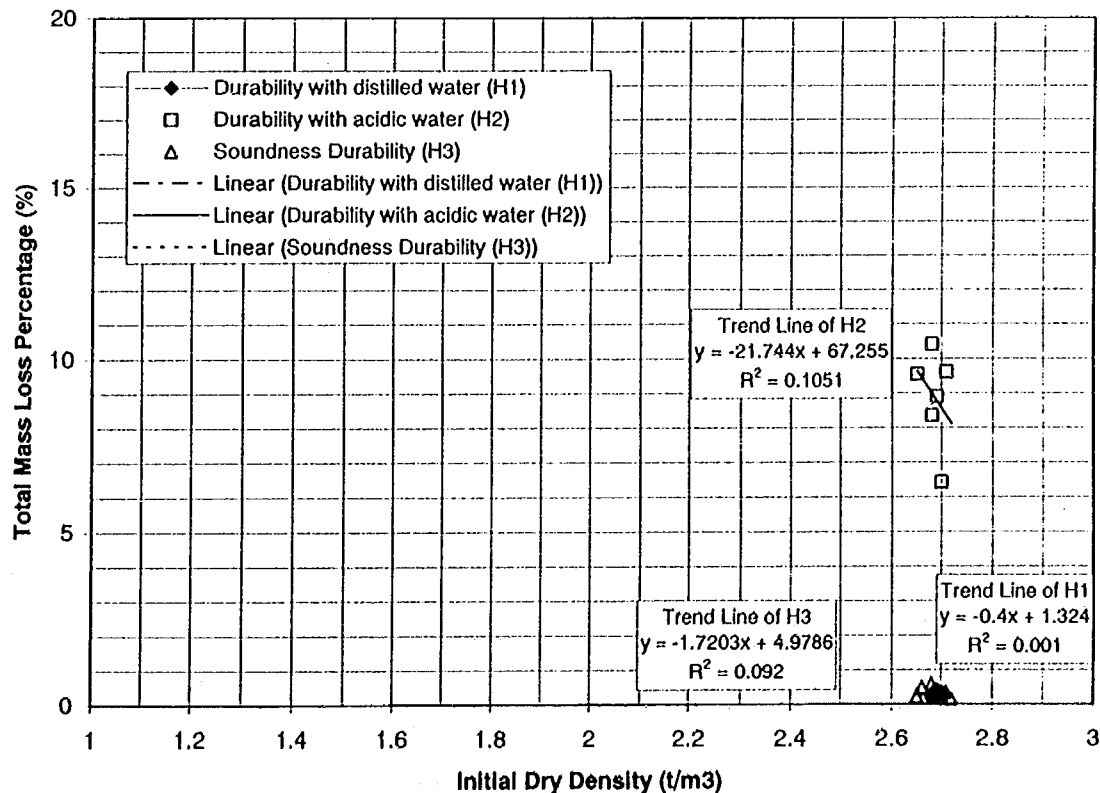


Figure 10 Trend lines of total mass loss percentages of studied samples after different durability tests in function of initial water absorption.

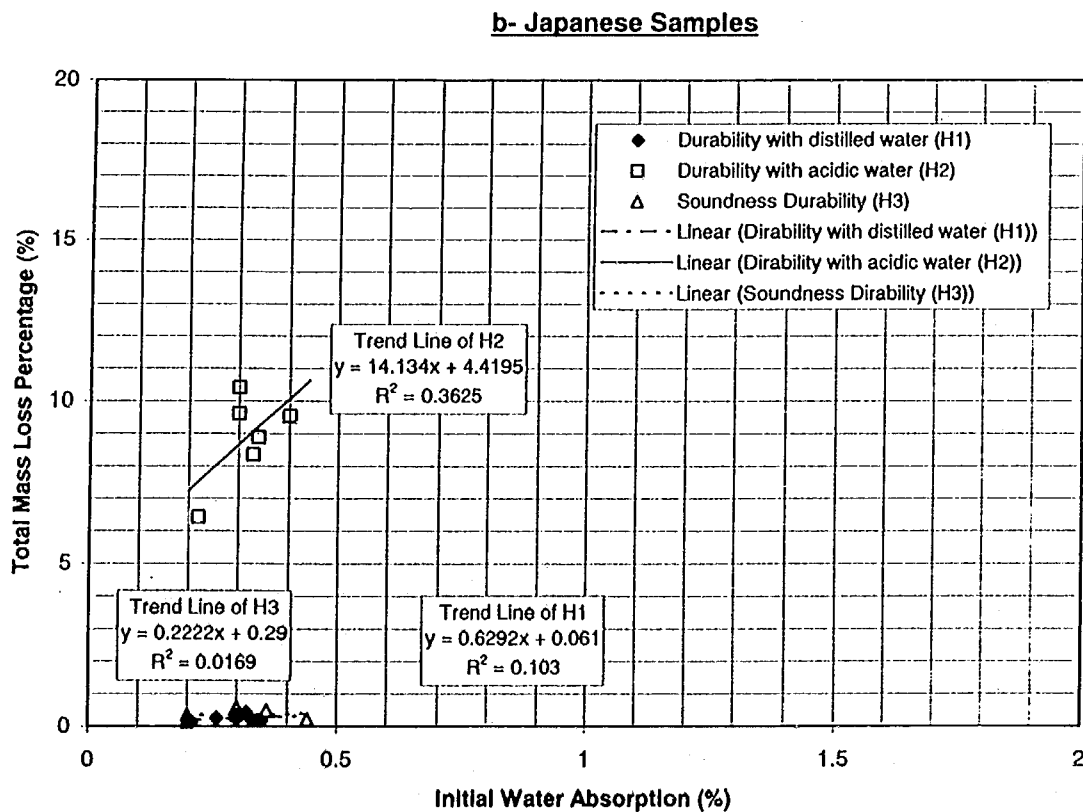
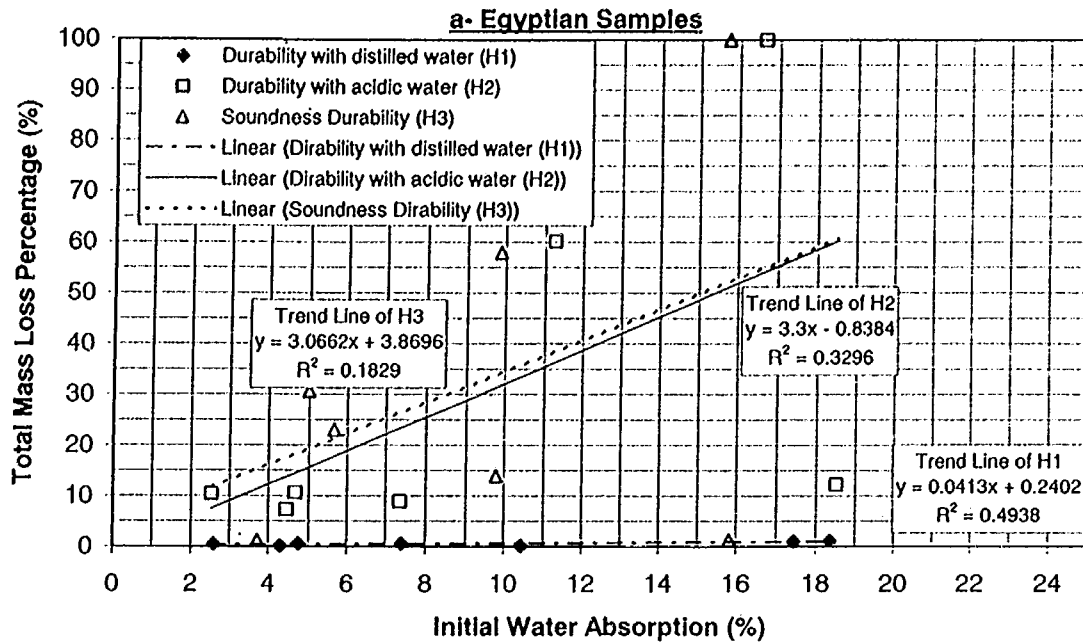


Figure 11 Trend lines of total mass loss percentages of studied samples after different durability test in function of initial porosity.

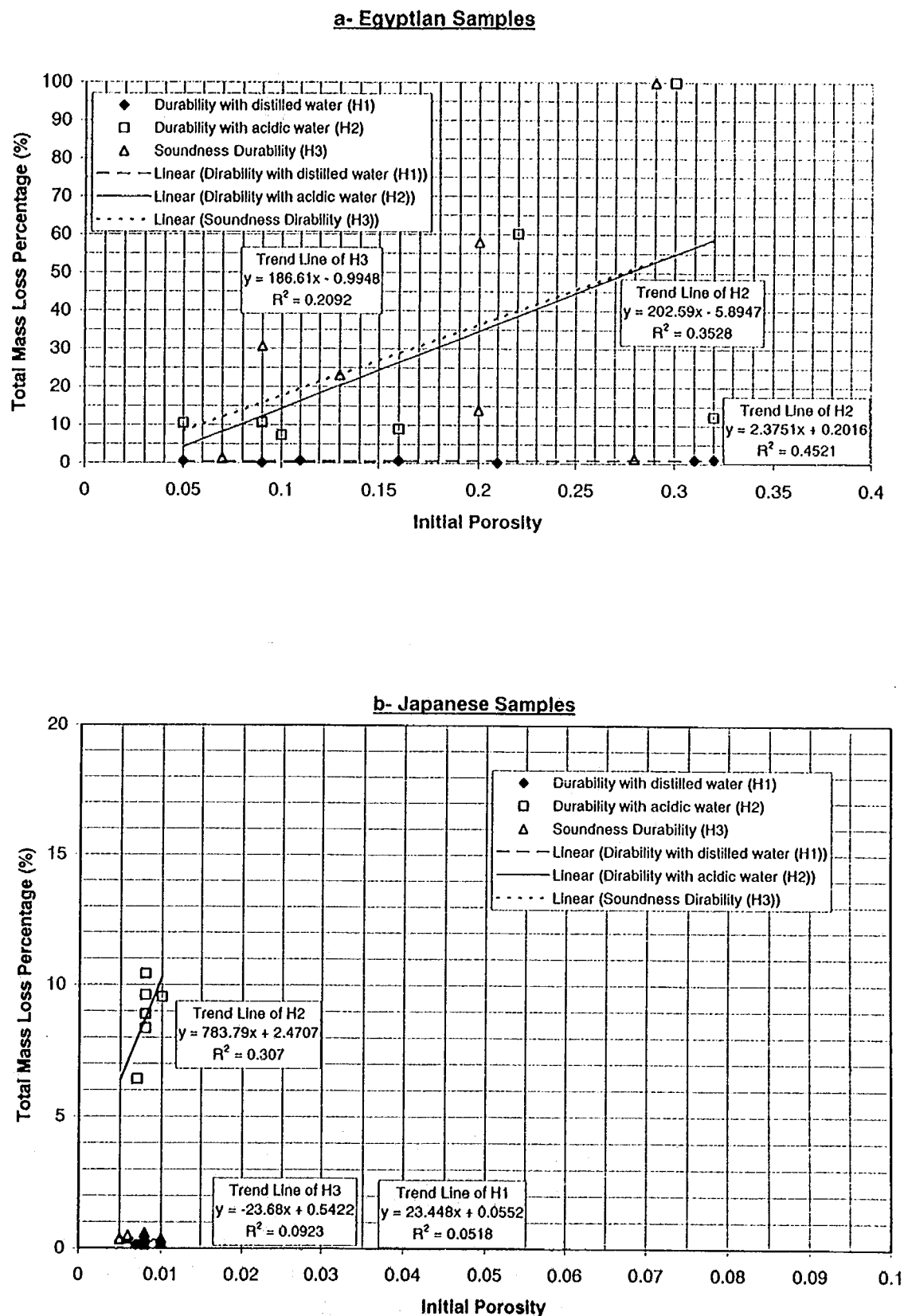
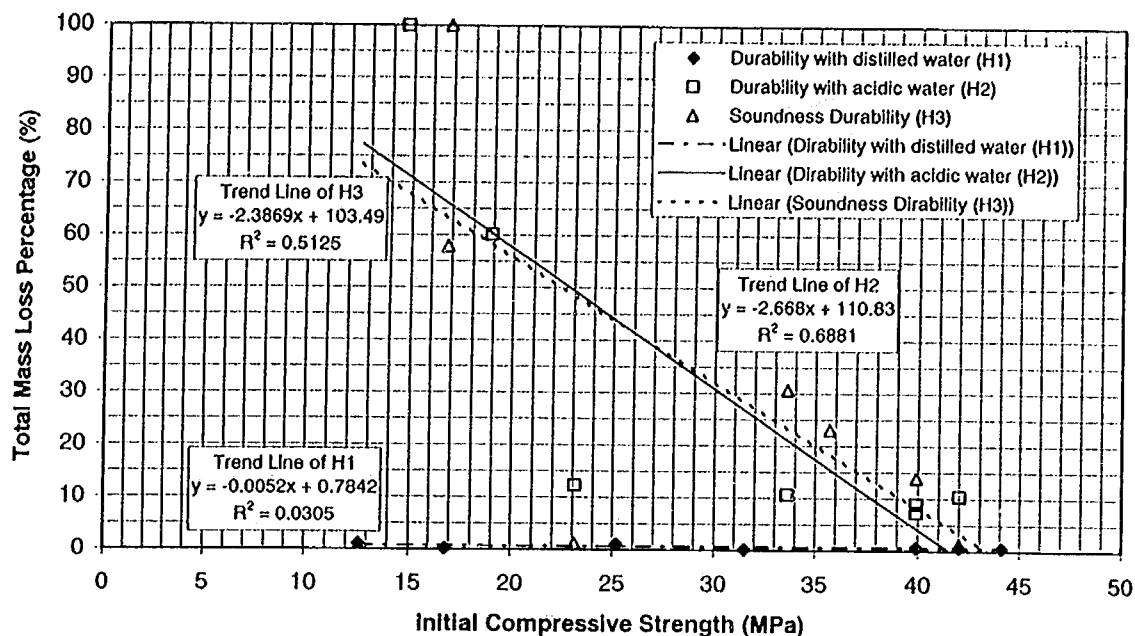


Figure 12 Trend lines of total mass loss percentages of studied samples after different durability tests in function of initial compressive strength.

a- Egyptian Samples



b- Japanese Samples

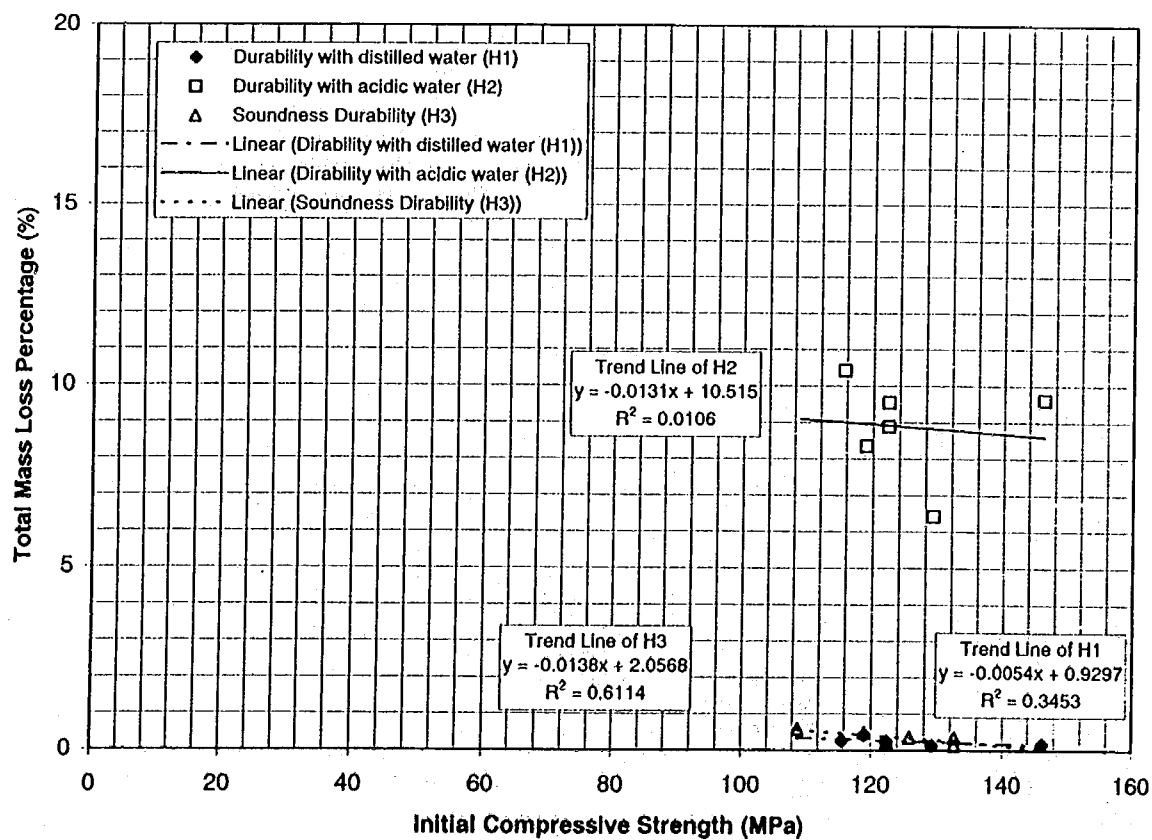
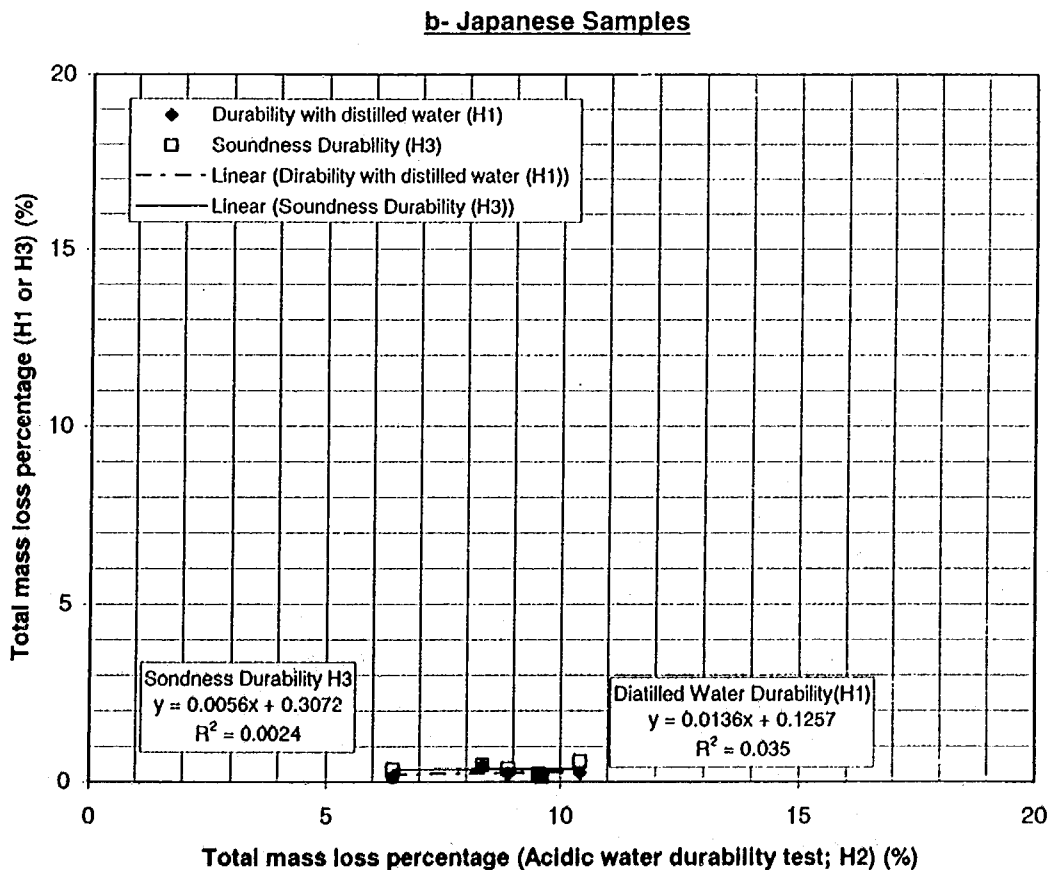
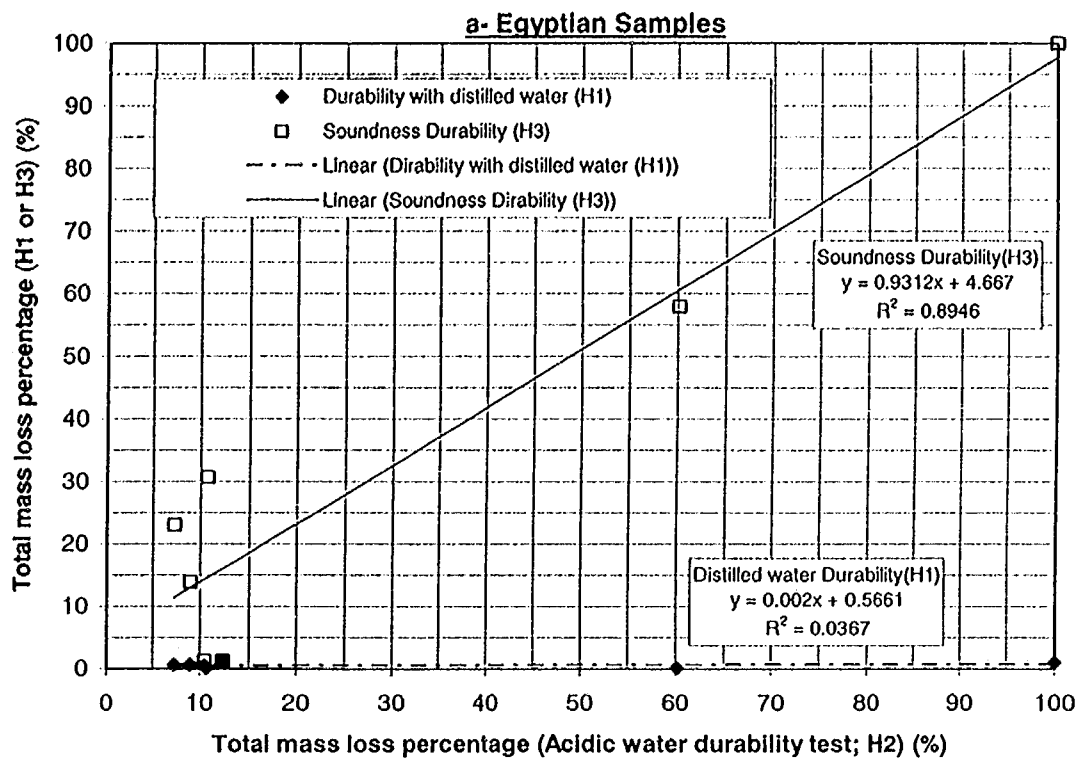


Figure 13 Relationship between total loss percentages of studied samples for the different types of durability test.



durability test is constructed in Figure 13. From this figure, it could be noticed that the closed and forced relationship between the results of acidic and soundness durability tests. The relation coefficient of this relation attained 0.9. These observations are valid only to the Egyptian limestone rather than the Japanese limestone which could need more cycles due to their high durability.

4.2 Mineral compositions

The mineral compositions of the studied sample before and after the acidic durability test are shown in Table 6 and Figure 14. From this table, the dominant minerals of Egyptian intact limestone are in the following order: calcite, dolomite and quartz, whereas those of Japanese limestone are: calcite and dolomite. However the minerals of final weathered products of Egyptian limestone changed to the following order: anhydrite, bassanite, gypsum, calcite and quartz, whereas those of Japanese limestone changed to the following order: anhydrite and gypsum. It is mean that the Egyptian and Japanese mineral compositions and consequently their behaviors are completely different.

The initial and final states of the intact studied samples as well as the thin section photomicrographs of the intact samples and the final weathered product after acidic durability test are enclosed in an adjoins plates of Appendix. From these plates, it is find in general that:

- 1) Egyptian limestone consist of highly porous and fossiliferous grains of fine calcite, some quartz and dolomite.
- 2) Japanese limestone consist of very dense and highly crystalline calcite and dolomite

Table 6 Mineral compositions of studied powder samples.

Sample Type	Initial Powder			Final Weathered Product after Acidic Durability Test				
	Quartz SiO ₂	Calcite CaCO ₃	Dolomite (Mg,Ca)CO ₃	Quartz SiO ₂	Calcite CaCO ₃	Anhydrite CaSO ₄	Gypsum CaSO ₄ . 2H ₂ O	Bassanite CaSO ₄ . 1/2H ₂ O
1(Egyptian)	+	+++++		+++	+	++	+++++	+++
2(Egyptian)	++	+++++		++	++++	+++++		++++
3(Egyptian)		+++++	++			+++++	+	++
4(Egyptian)	++	+++++	+++	++	++++	+++++		++++
5(Egyptian)		+++++	+		+++	+++++		+++
6(Egyptian)		+++++	+		++	+++++	+	+++
7(Egyptian)	+	+++++	+++++	+++		+++++	+++	+++
8(Japanese)		+++++				+++++	++	
9(Japanese)		+++++				+++++	++	
10(Japanese)		+++++				+++++	+	
11(Japanese)		+++++	+			+++++	+	
12(Japanese)		+++++				+++++	+	
13(Japanese)	+	+++++	+++++	+		+++++	+	

* The relative contents of mineral compositions were based on the strongest peak of each mineral as follows:

+++++ $\cong$ 2,000 cps (counts per second)

++++ $\cong$ 1,000 cps

+++ $\cong$ 500 cps

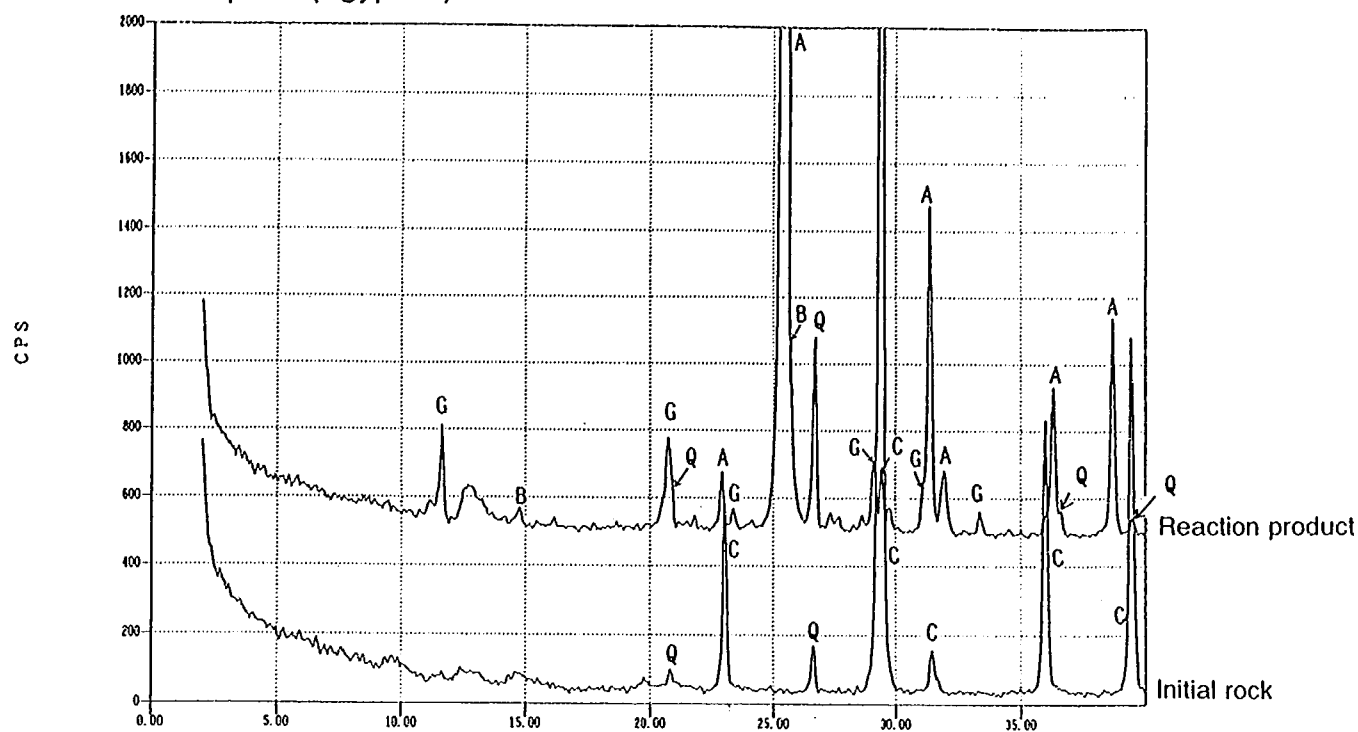
++ $\cong$ 250 cps

+ $\cong$ 0 cps

Figure 14 X-ray diffraction patterns of initial studied samples and reaction product by acidic solution durability test.

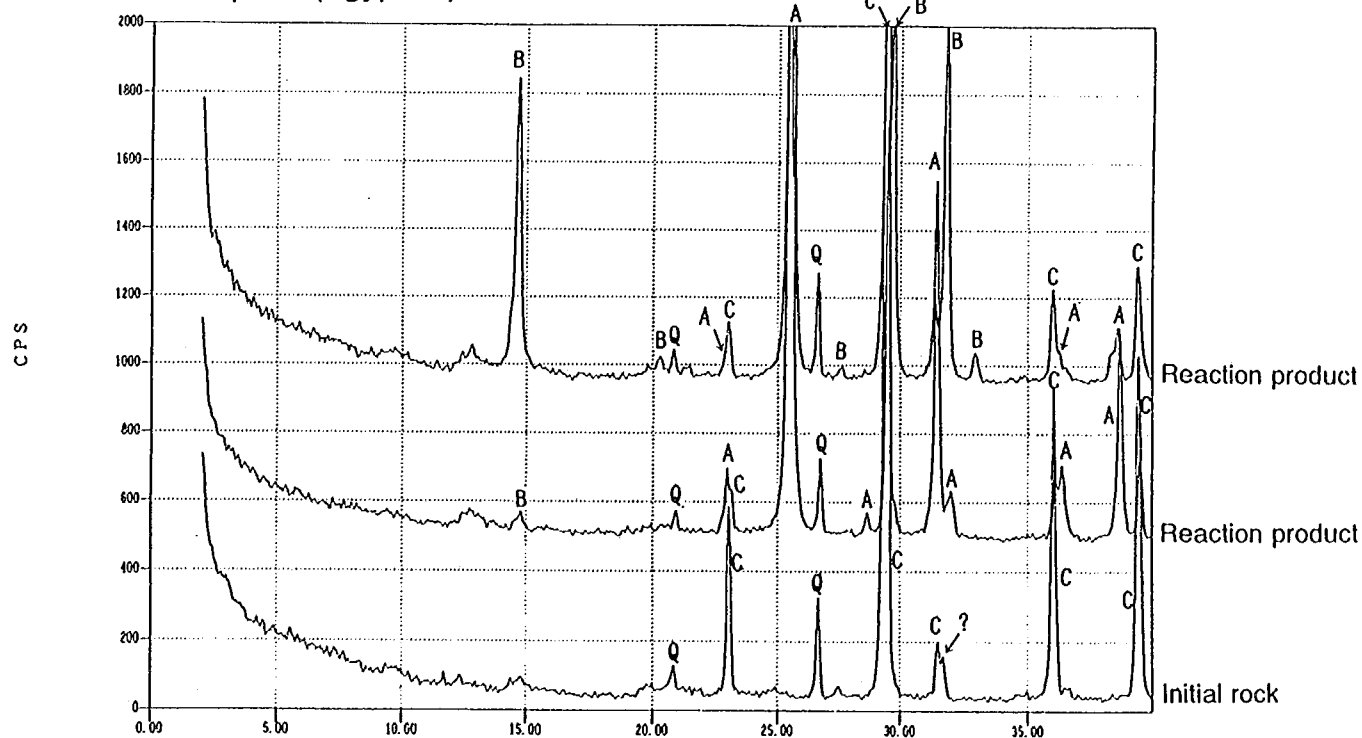
A: anhydrite, B: bassanite, C: calcite, D: dolomite, G: gypsum, Q: quartz

Sample-1 (Egyptian)



20

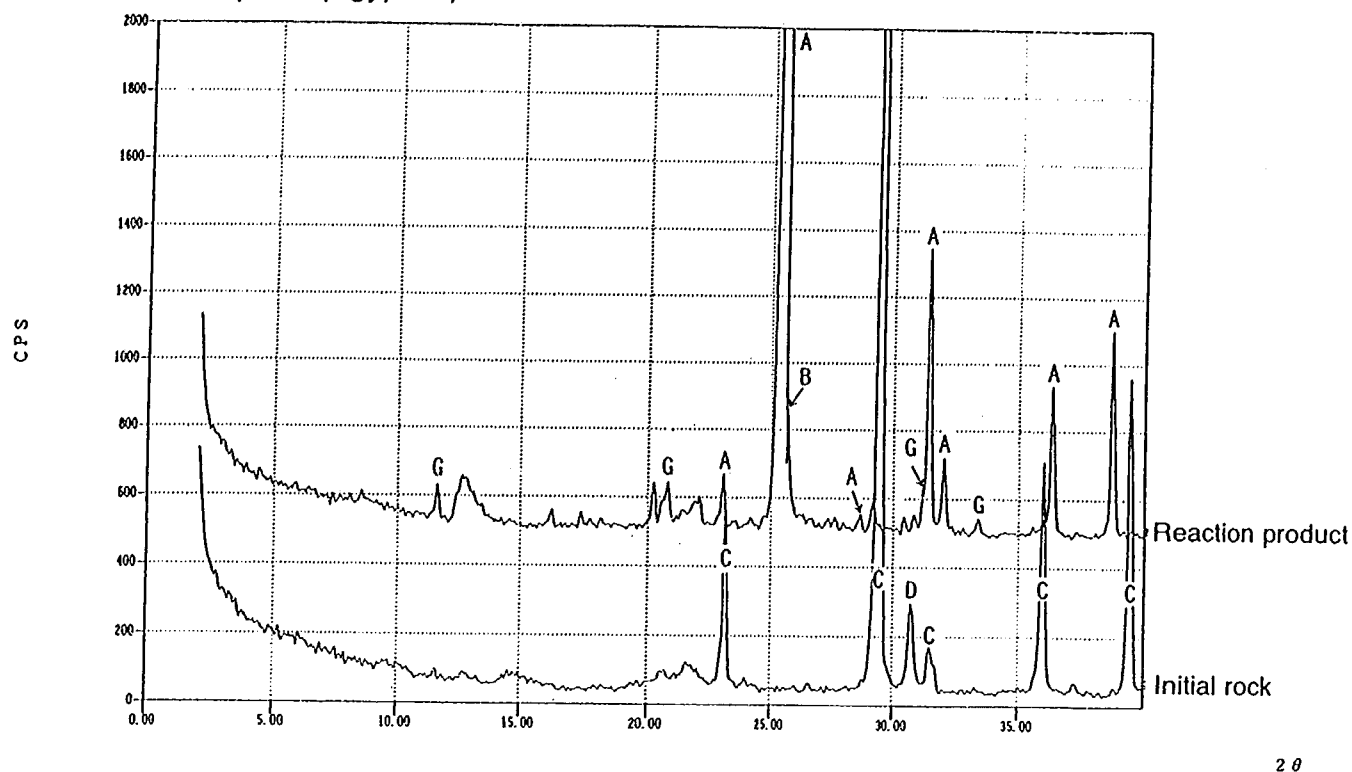
Sample-2 (Egyptian)



20

Figure 14 X-ray diffraction patterns of initial studied samples and reaction product by acidic solution durability test (Continued).

Sample-3 (Egyptian)



Sample-4 (Egyptian)

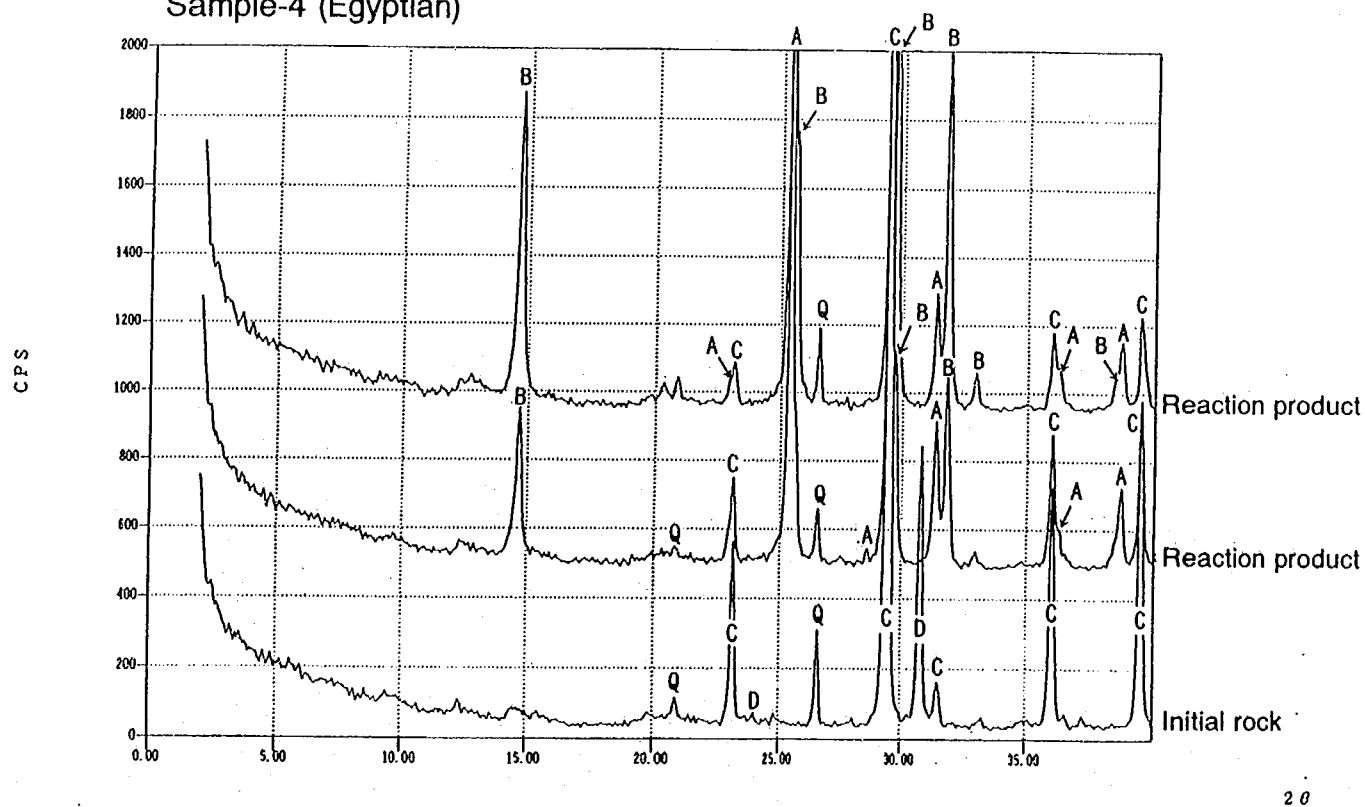
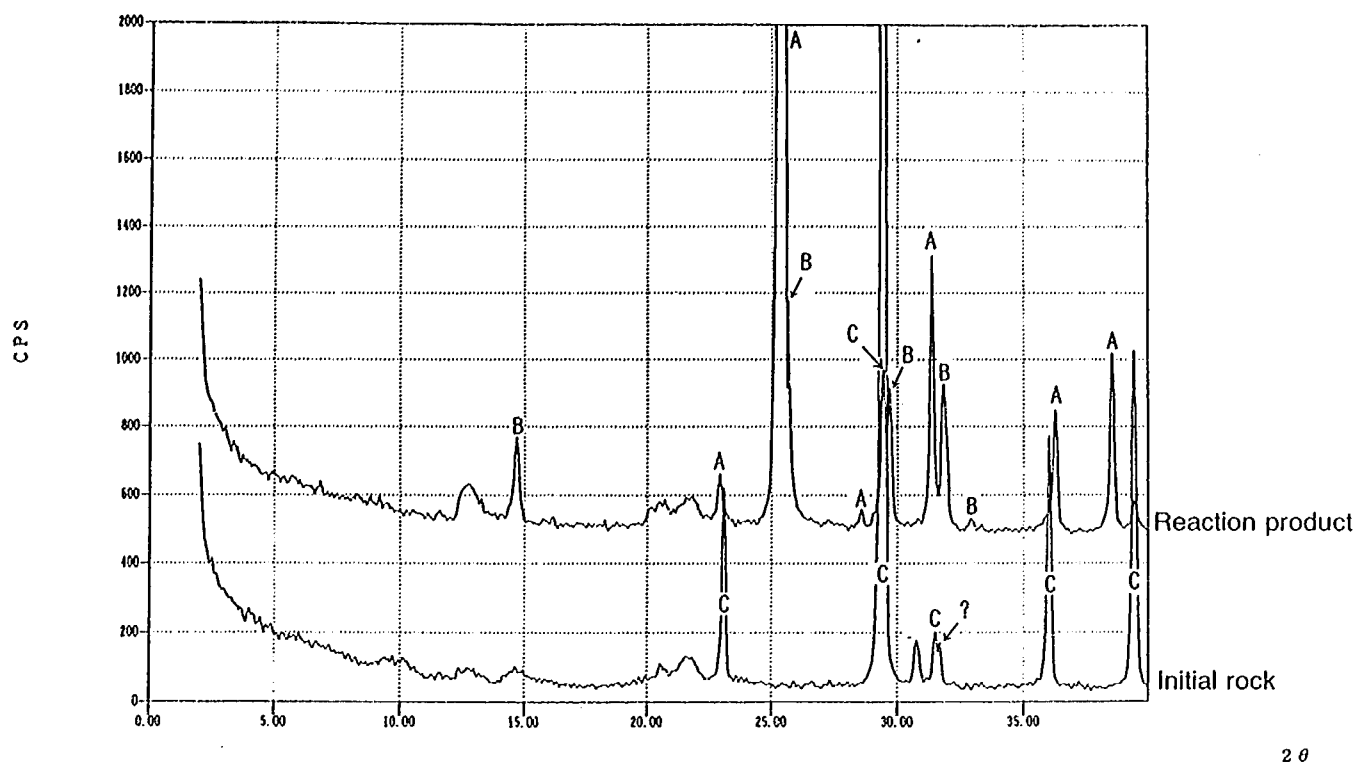


Figure 14 X-ray diffraction patterns of initial studied samples and reaction product by acidic solution durability test (Continued).

Sample-5 (Egyptian)



Sample-6 (Egyptian)

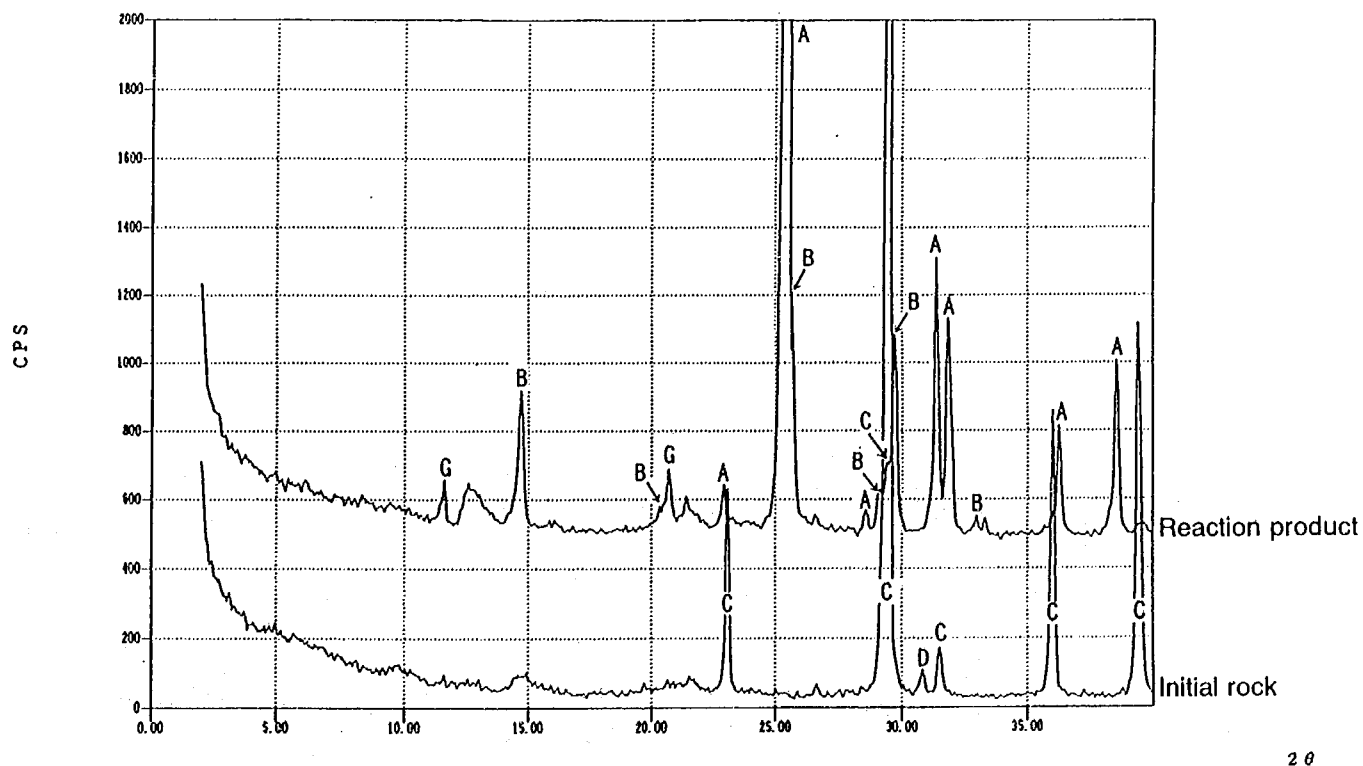
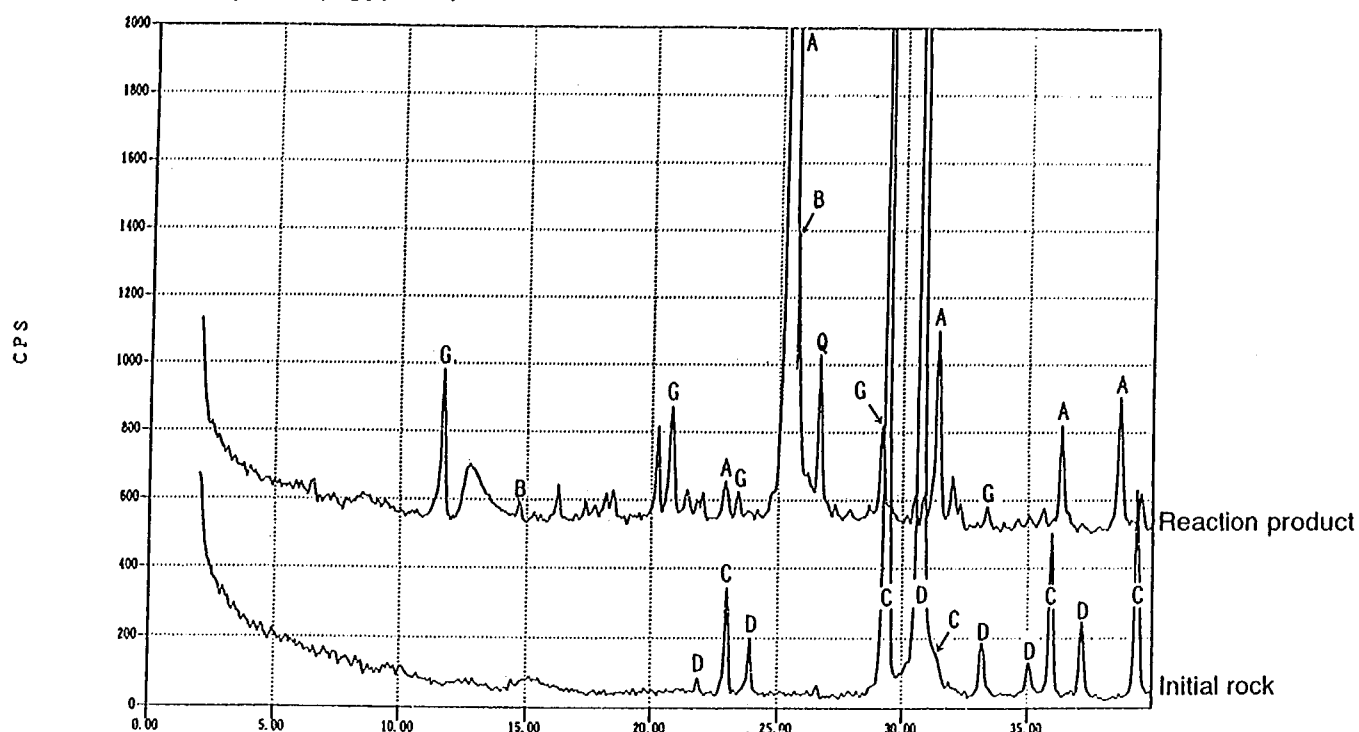


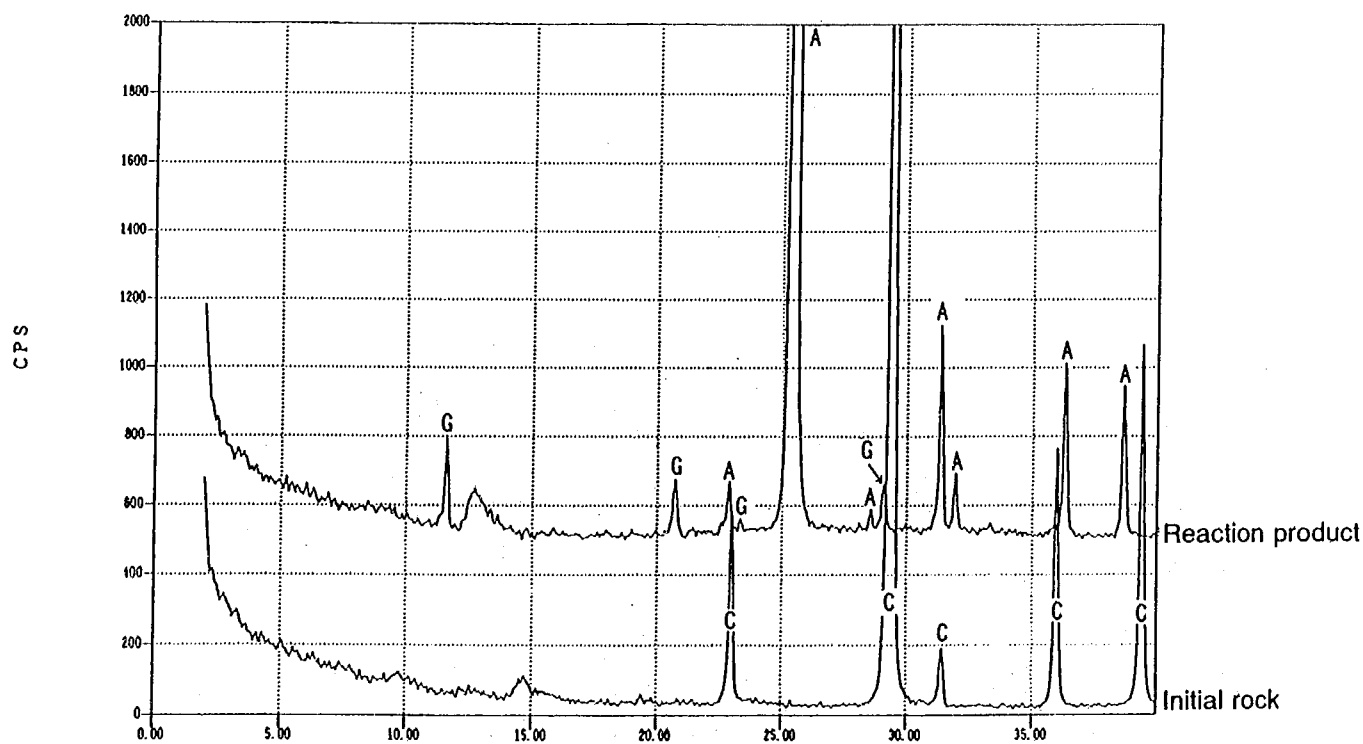
Figure 14 X-ray diffraction patterns of initial studied samples and reaction product by acidic solution durability test (Continued).

Sample-7 (Egyptian)



20

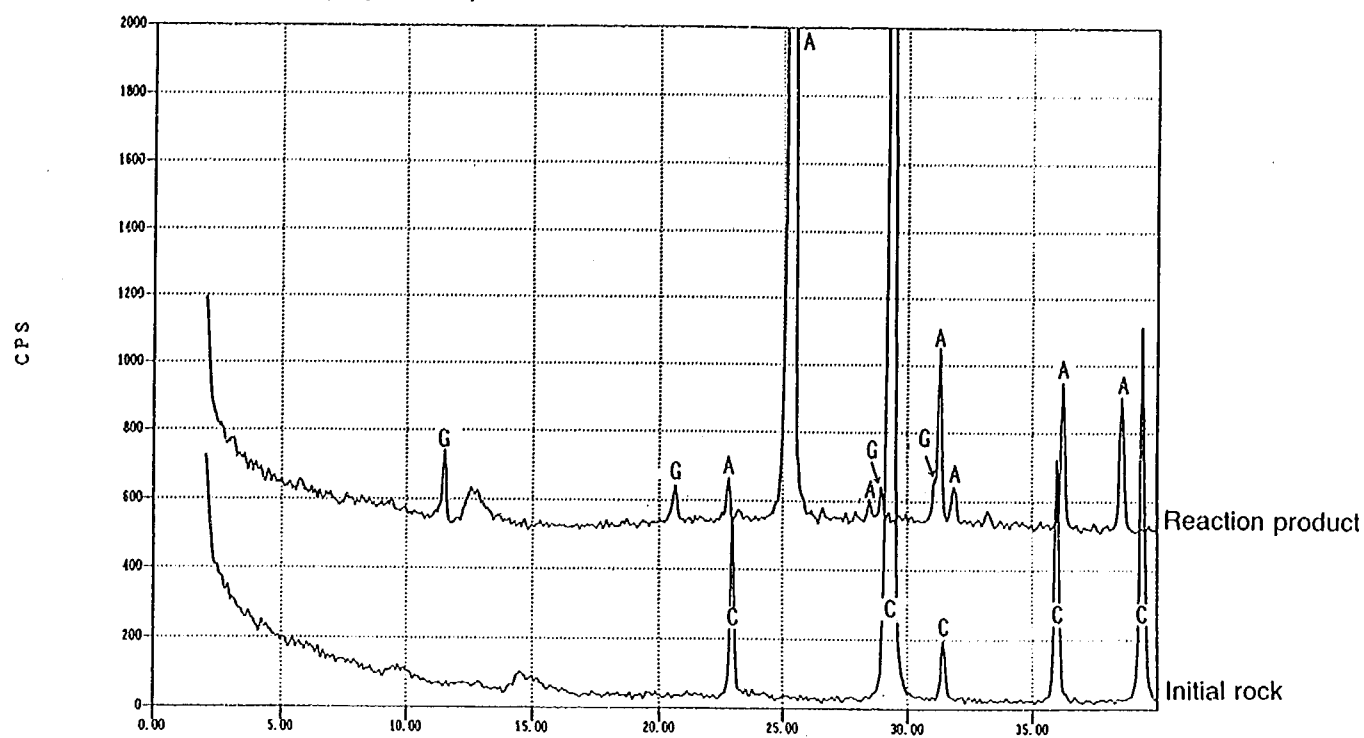
Sample-8 (Japanese)



20

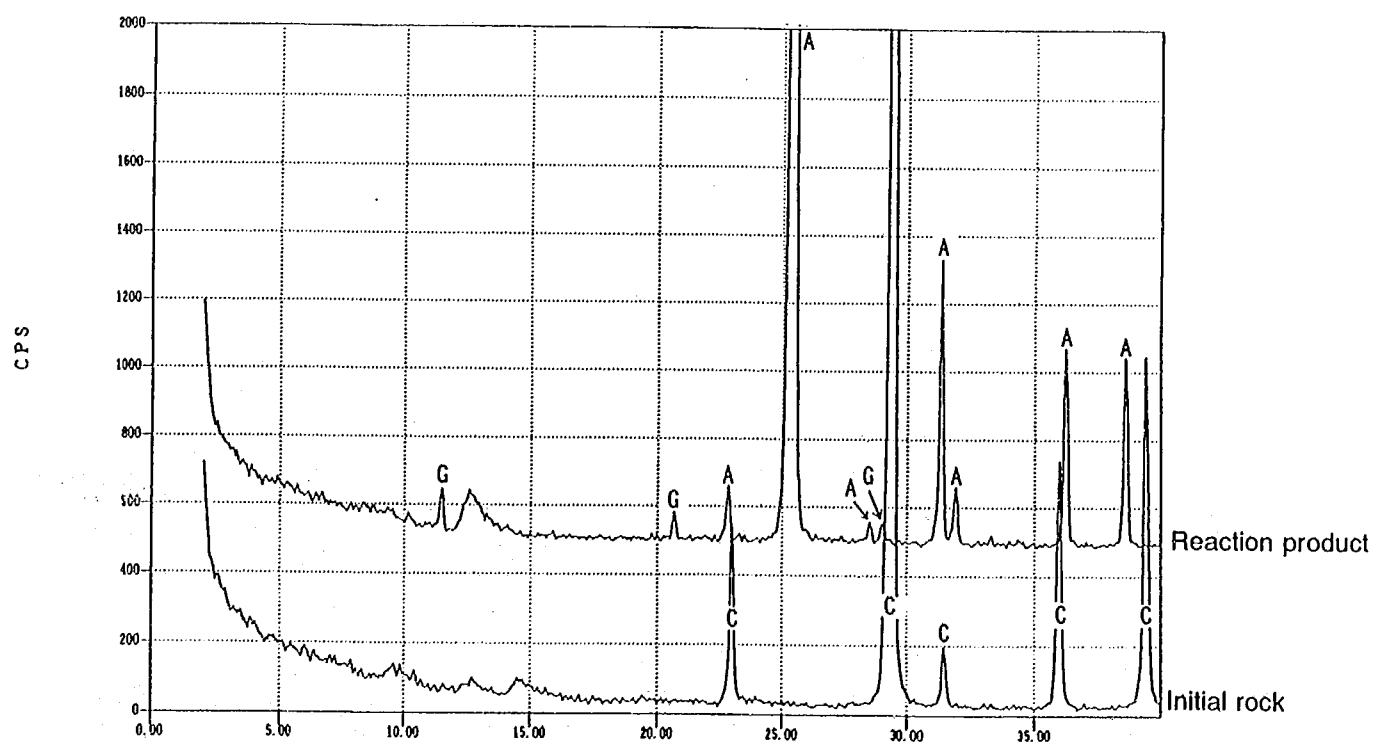
Figure 14 X-ray diffraction patterns of initial studied samples and reaction product by acidic solution durability test (Continued).

Sample-9 (Japanese)



20

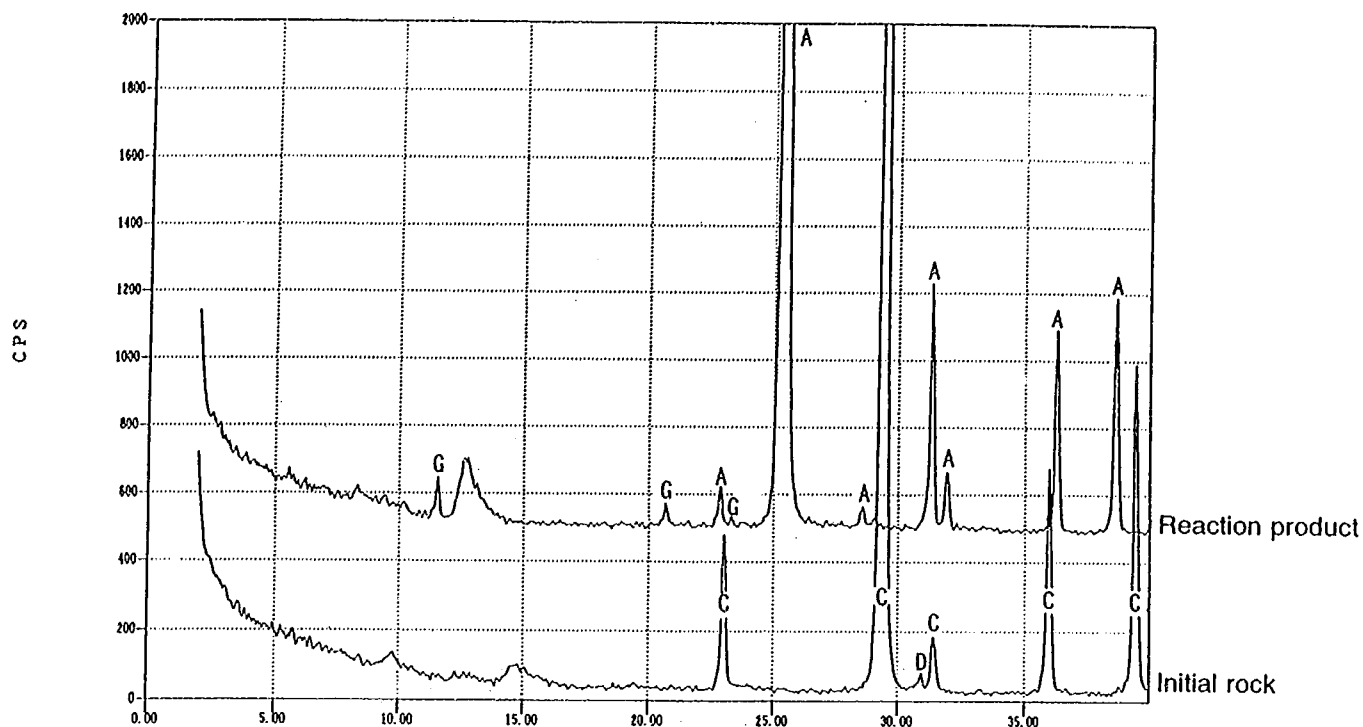
Sample-10 (Japanese)



20

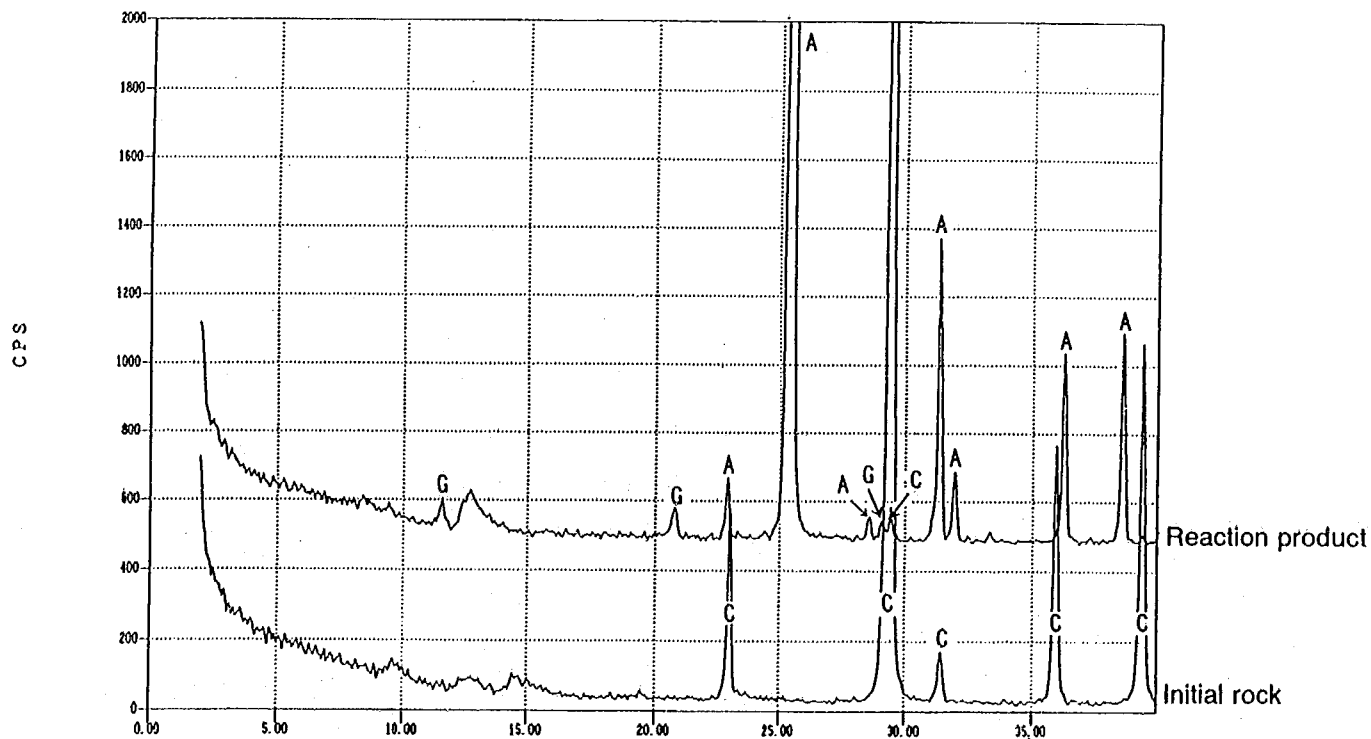
Figure 14 X-ray diffraction patterns of initial studied samples and reaction product by acidic solution durability test (Continued).

Sample-11 (Japanese)



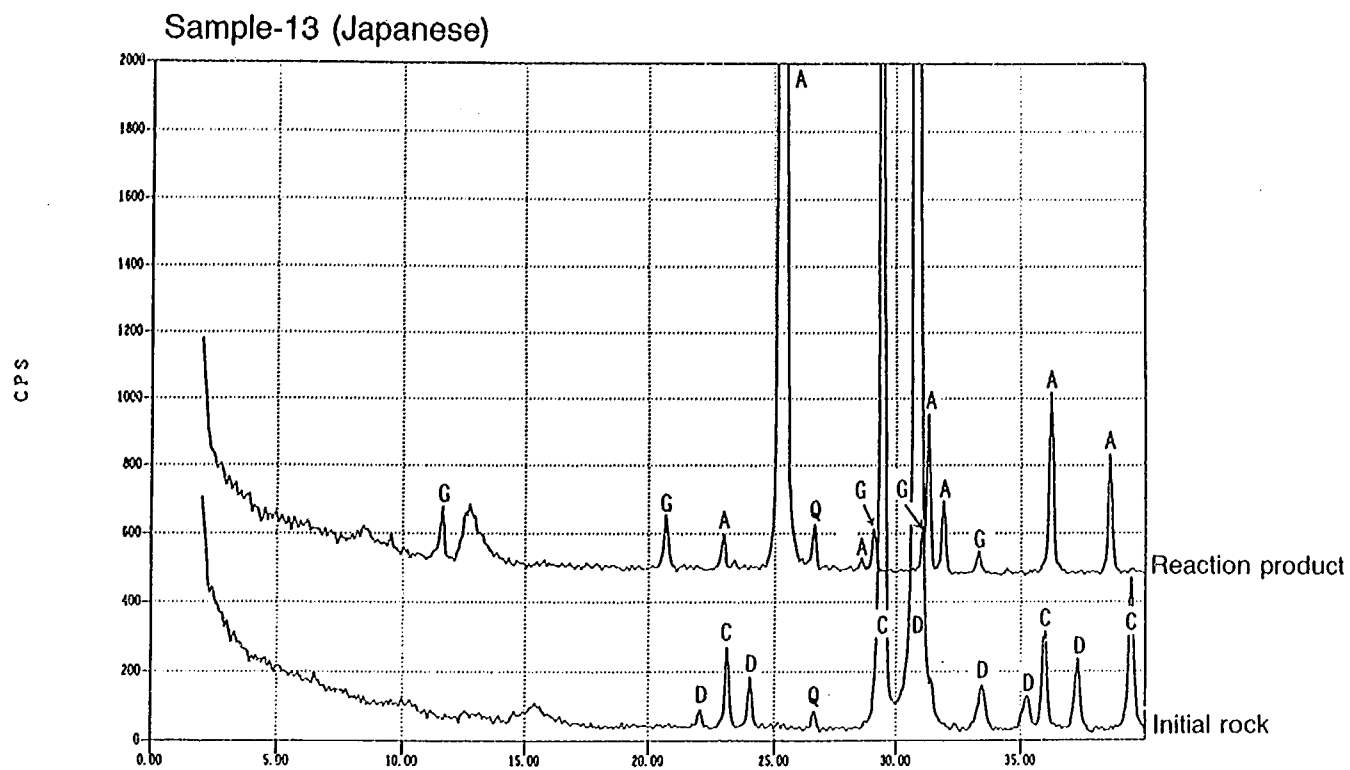
20

Sample-12 (Japanese)



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Figure 14 X-ray diffraction patterns of initial studied samples and reaction product by acidic solution durability test (Continued).



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5. CONCLUSIONS

From the obtained results and the previous analysis the following points can be concluded:

- 1) Egyptian building limestone is completely different from Japanese limestone texturally and compositionally. The Egyptian limestone consists of highly porous and fossiliferous grains of fine calcite. The Japanese limestone consists of a very dense and closed highly crystalline grains of calcite and dolomite. According to their basic properties and to the ISRM classification, the Egyptian limestone is considered as a weak rock but the Japanese limestone is considered as a strong rock.
- 2) The effect of durability tests on behaviors of Egyptian limestone is different from their effect on Japanese samples. However there is some common trend of the acidic and soundness test with their basic properties with a lower degree in the case of Japanese type.
- 3) The trend line of mass loss percentages of the durability test correlated to their basic initial properties is according to the following order: compressive strength, porosity, water absorption and dry density.
- 4) The simple, fast and representative laboratory test to obtain some good idea about the durability of building limestone especially for the Egyptian limestone is the soundness durability test. It has a good and closed relationship with the acidic durability test which costly and need more time.

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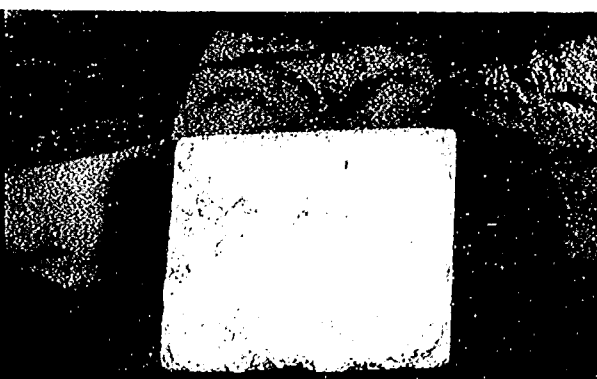
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APPENDIX

Plate 1 Initial and final states of sample No.1 for the different durability tests.

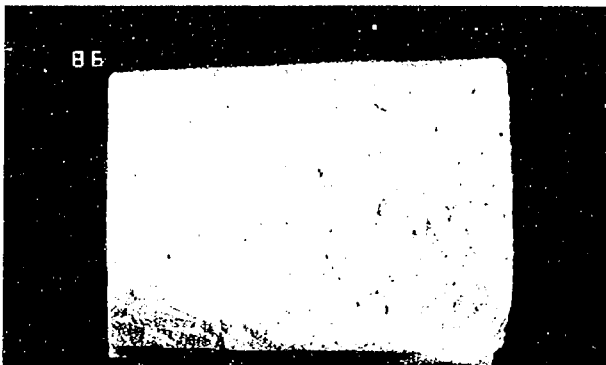
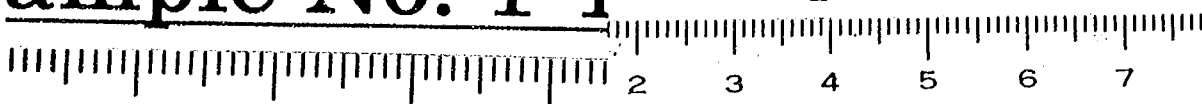
Initial state

Final state



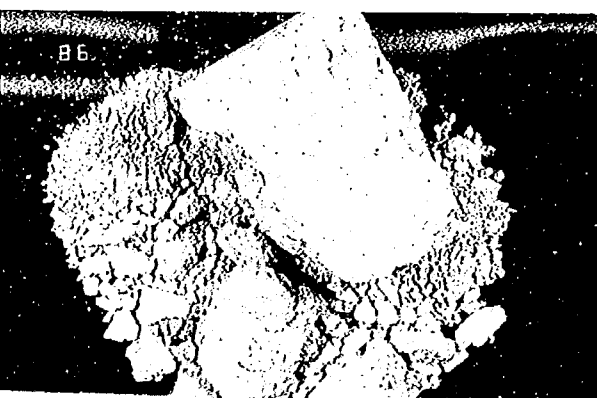
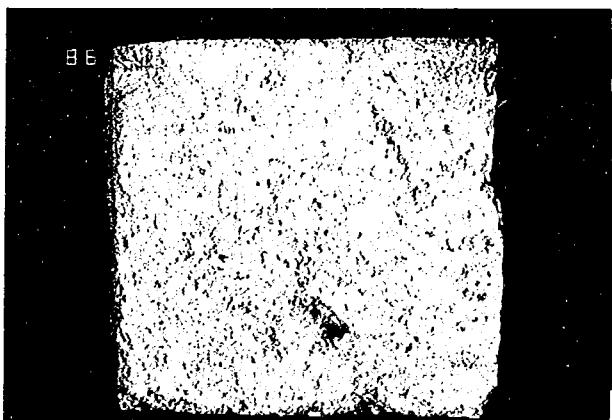
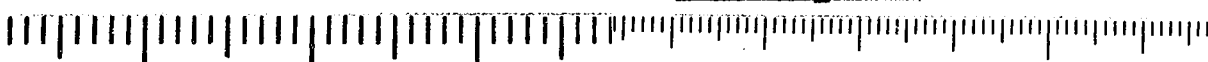
Sample No. 1-1

Sample No. 1-1



Sample No. 1-2

Sample No. 1-2



Sample No. 1-3

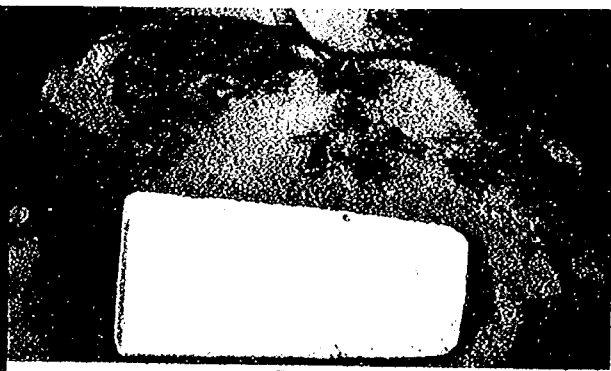
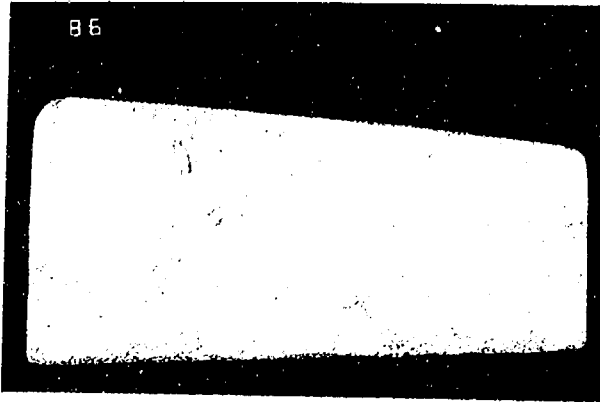
Sample No. 1-3



Plate 2 Initial and final states of sample No.2 for the different durability tests.

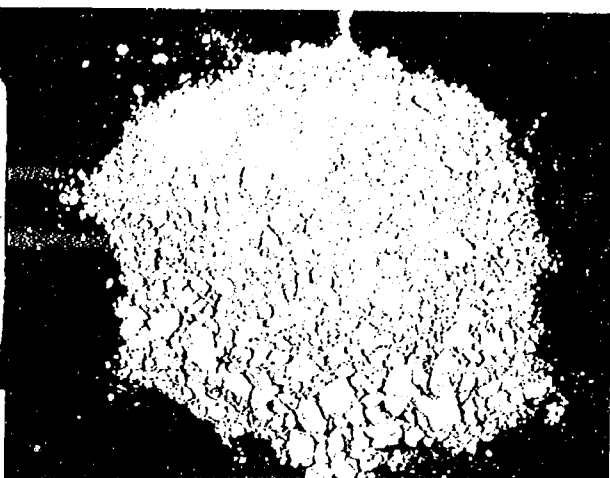
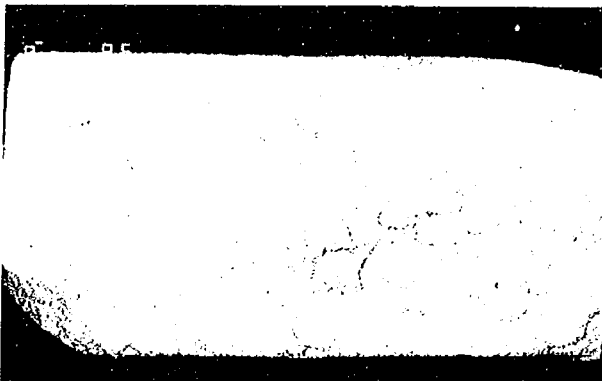
Initial state

Final state



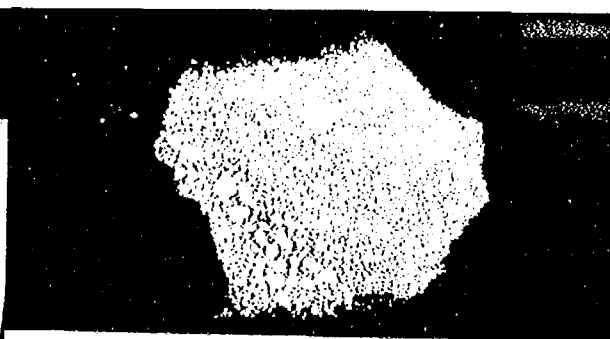
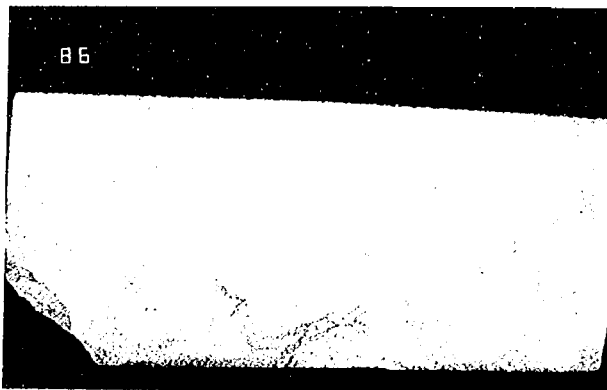
Sample No. 2-1

Sample No. 2-



Sample No. 2

Sample No. 2-2



Sample No. 2-3

Sample No. 2

Plate 3 Initial and final states of sample No.3 for the different durability tests.

Initial state

Final state

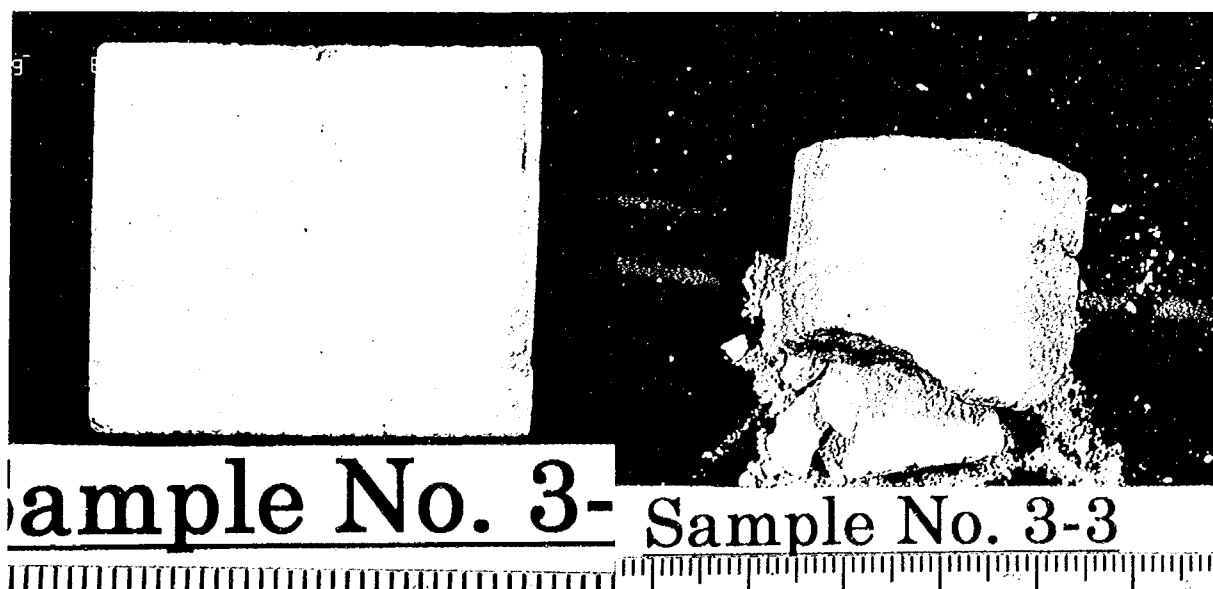
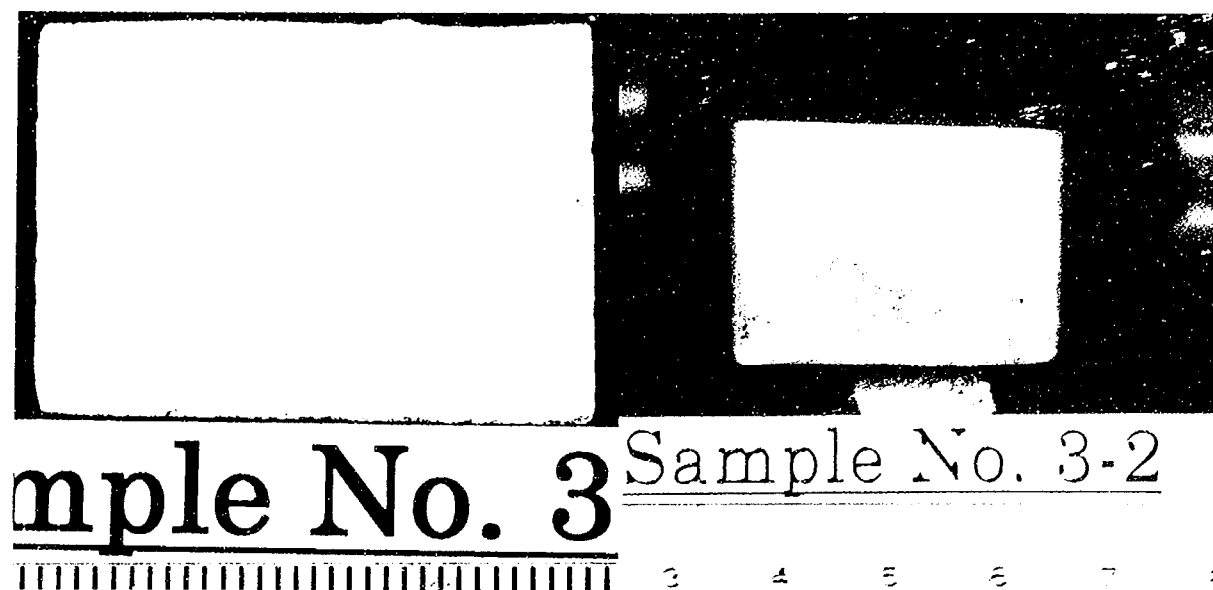
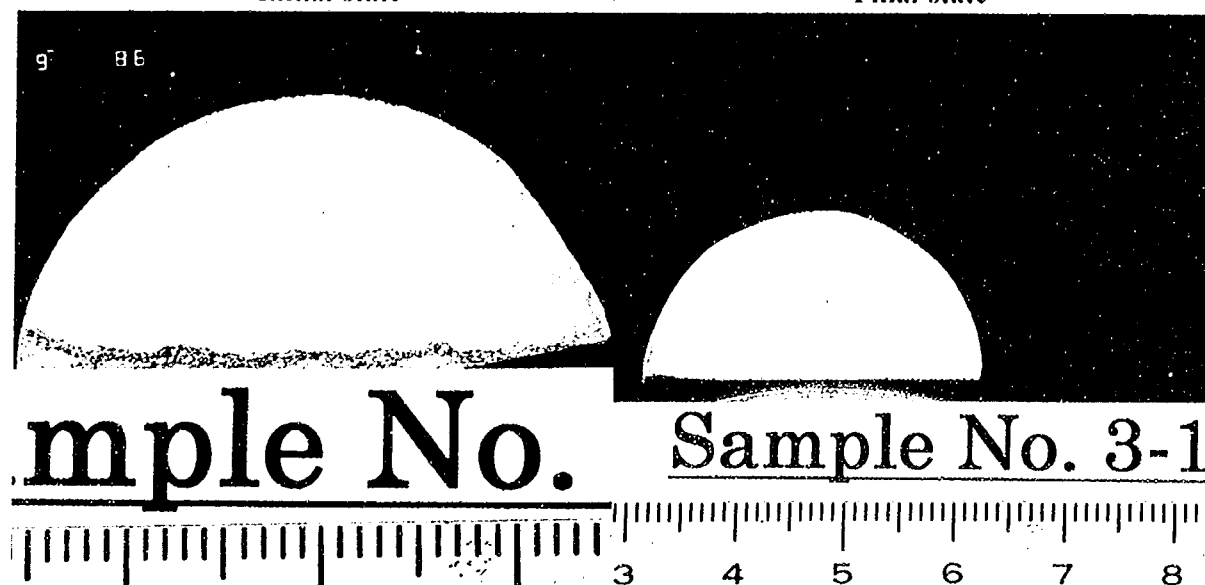


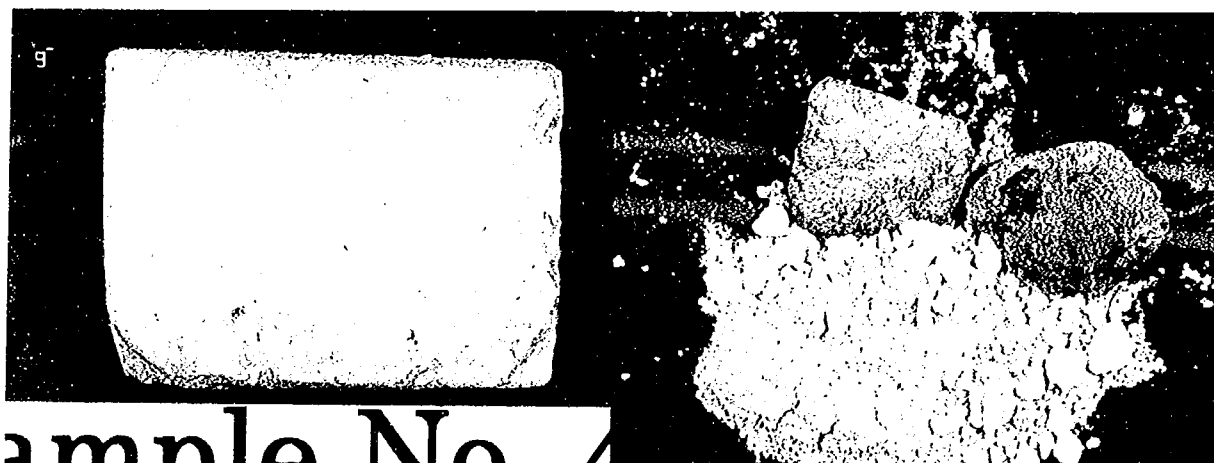
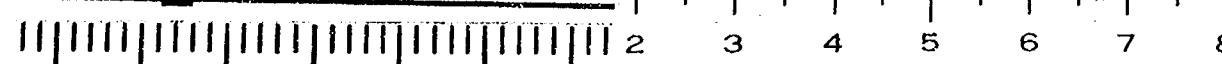
Plate 4 Initial and final states of sample No.4 for the different durability tests.

Initial state

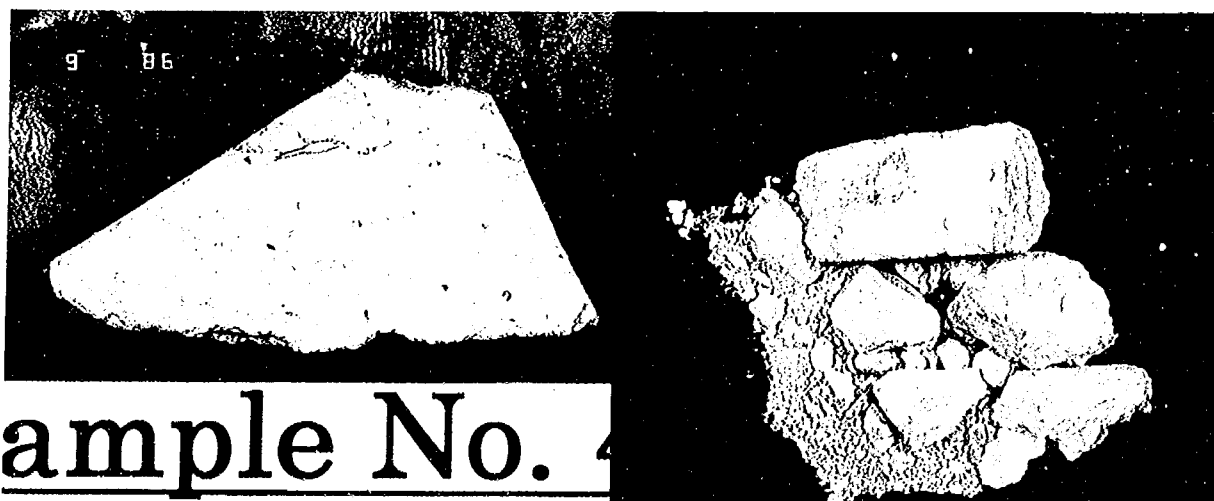
Final state



Sample No. 4-1



Sample No. 4-2



Sample No. 4-3



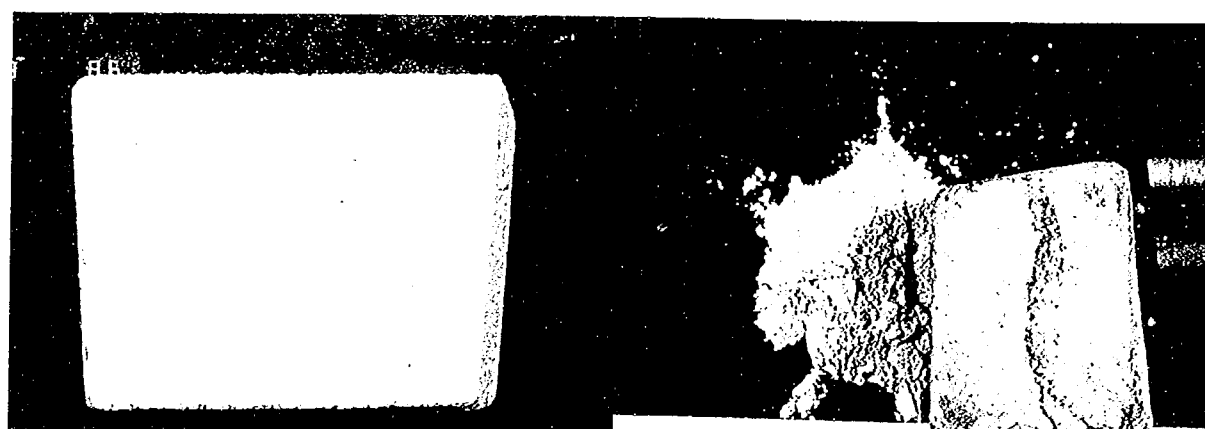
Plate 5 Initial and final states of sample No.5 for the different durability tests.

Initial state

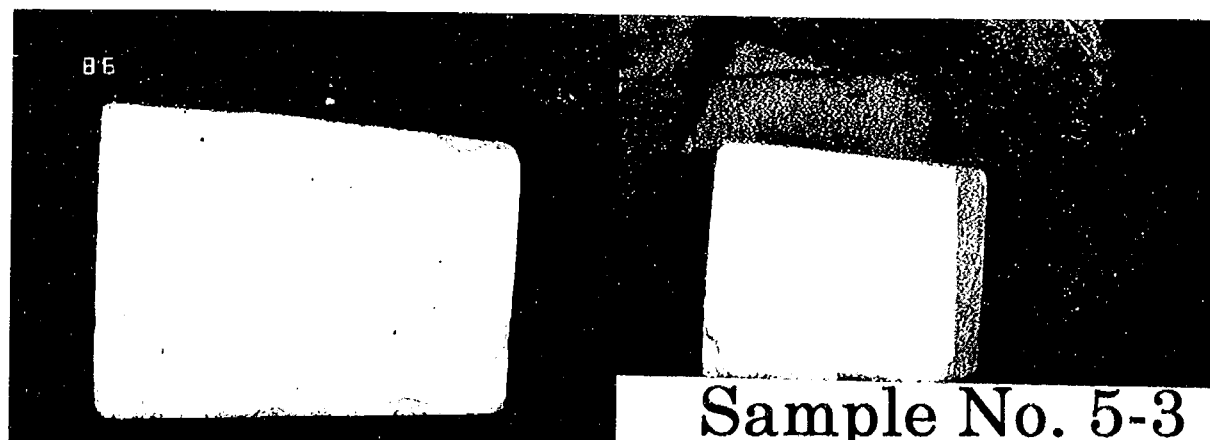
Final state



Sample No. 5-1



Sample No. 5-2

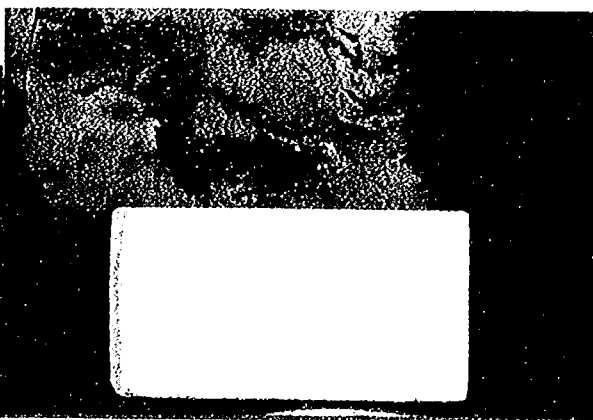
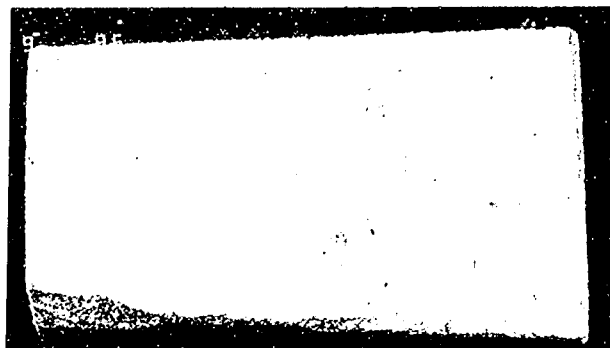


Sample No. 5-3

Plate 6 Initial and final states of sample No.6 for the different durability tests.

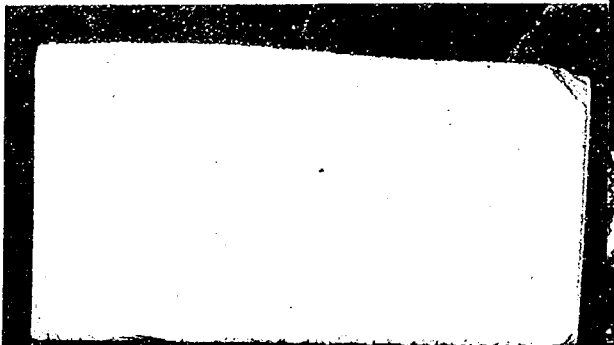
Initial state

Final state



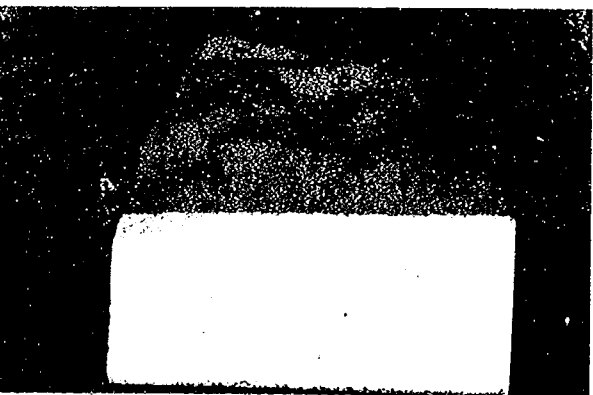
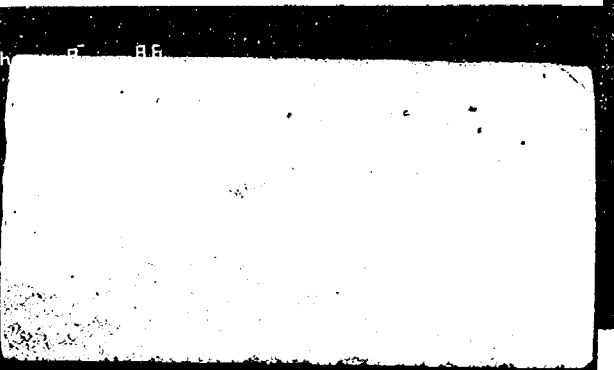
Sample No. 6

Sample No. 6-1



Sample No. 6-2

Sample No. 6-2



Sample No. 6-3

Sample No. 6-3



Plate 7 Initial and final states of sample No.7 for the different durability tests.

Initial state

Final state

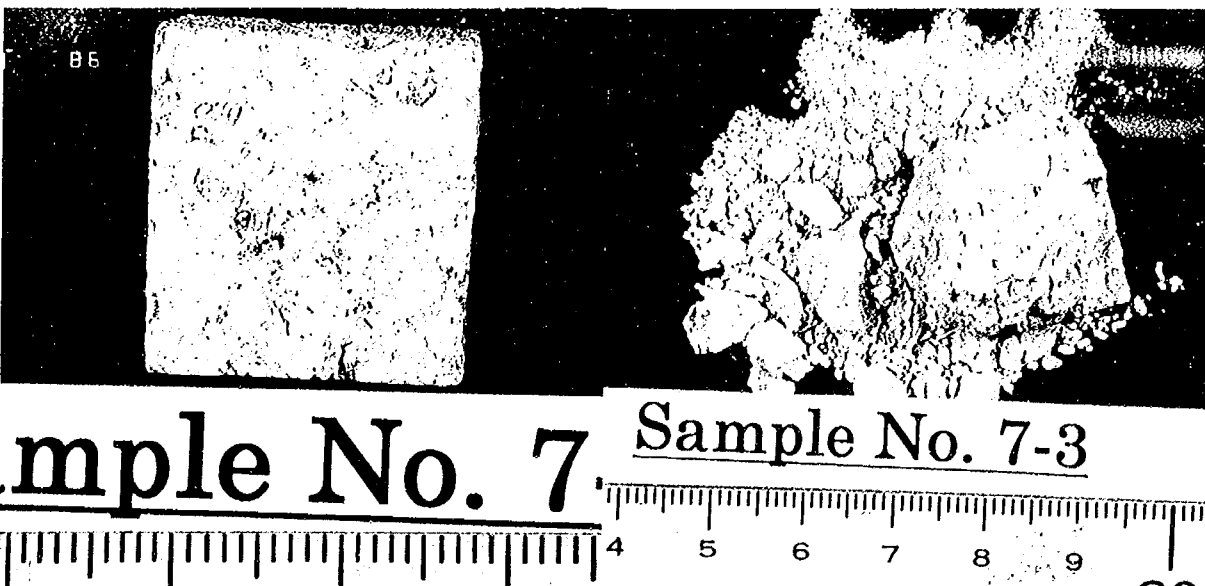
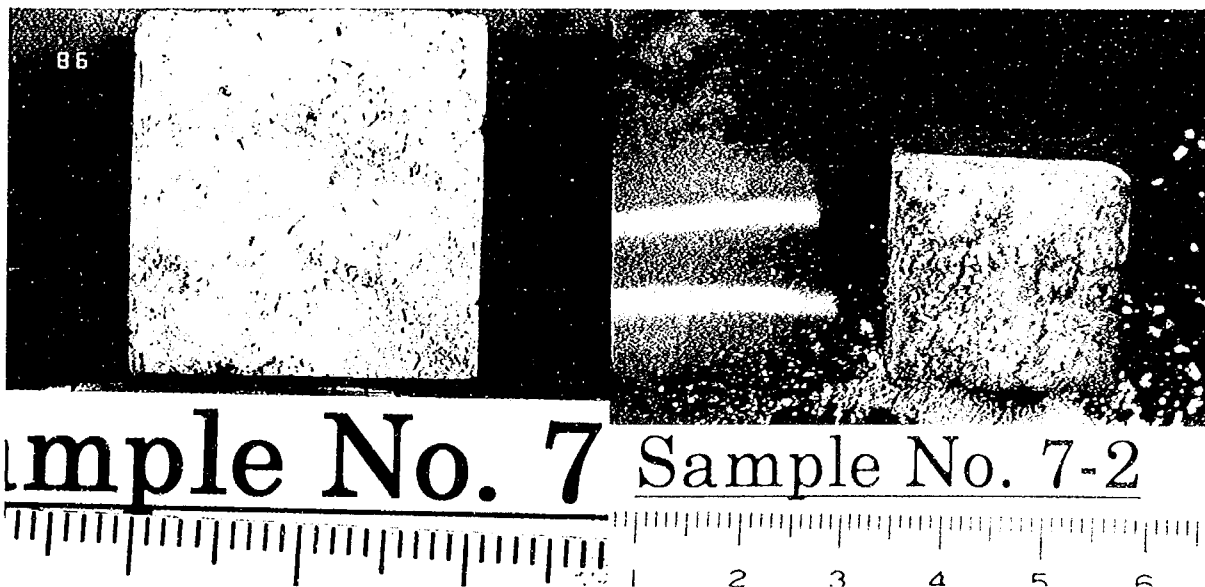
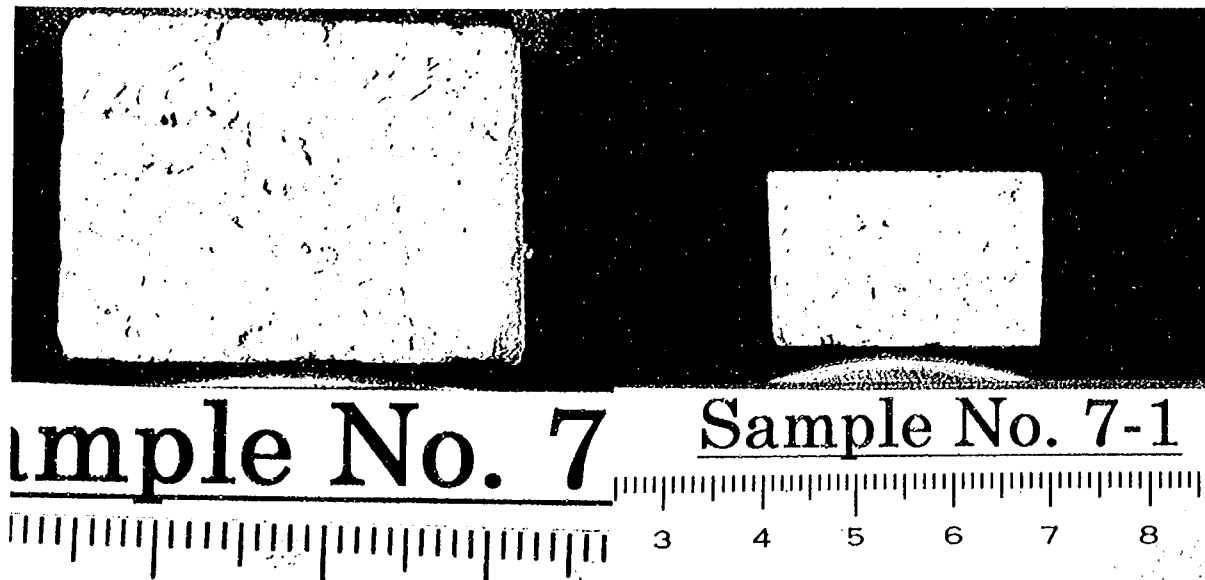


Plate 8 Initial and final states of sample No.8 for the different durability tests.

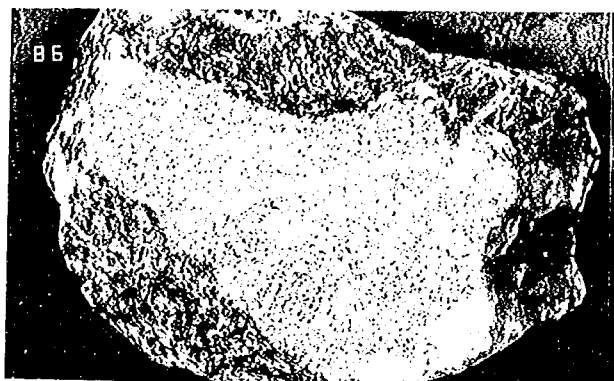
Initial state

Final state



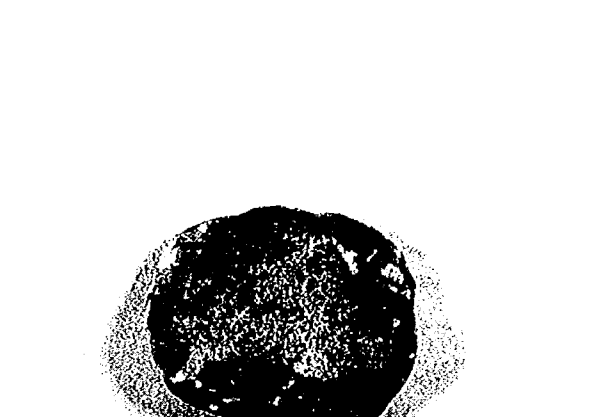
Sample No. 8

Sample No. 8-1



Sample No. 8

Sample No. 8-2



Sample No. 8

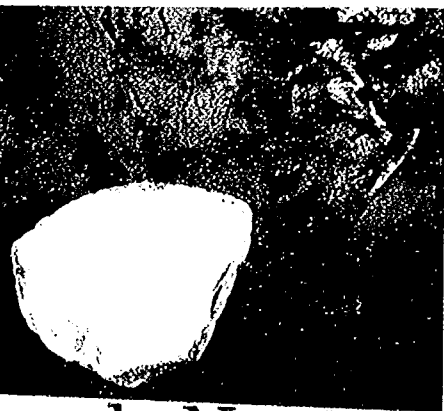
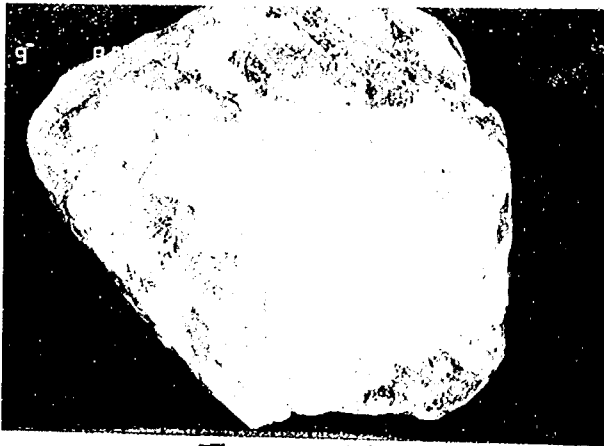
Sample No. 8-3



Plate 9 Initial and final states of sample No.9 for the different durability tests.

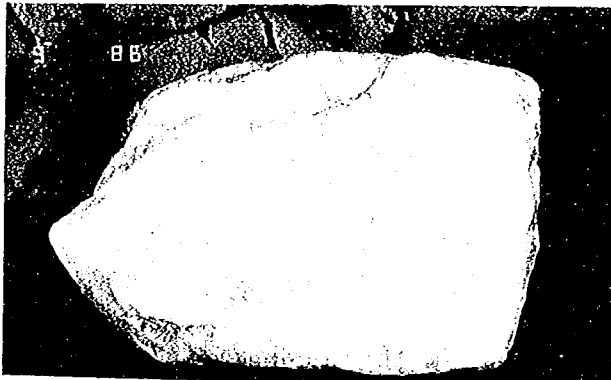
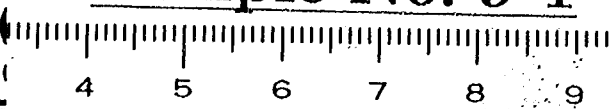
Initial state

Final state



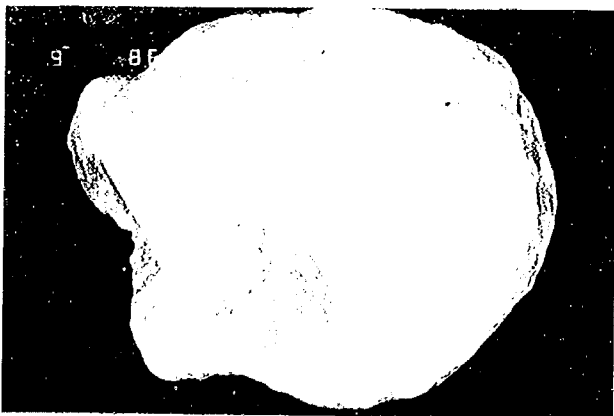
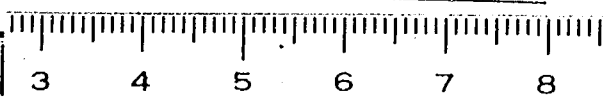
Sample No. 9-1

Sample No.



Sample No. 9-2

Sample No.



Sample No. 9-3

Sample No.

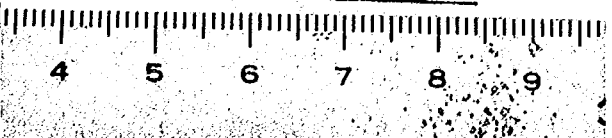
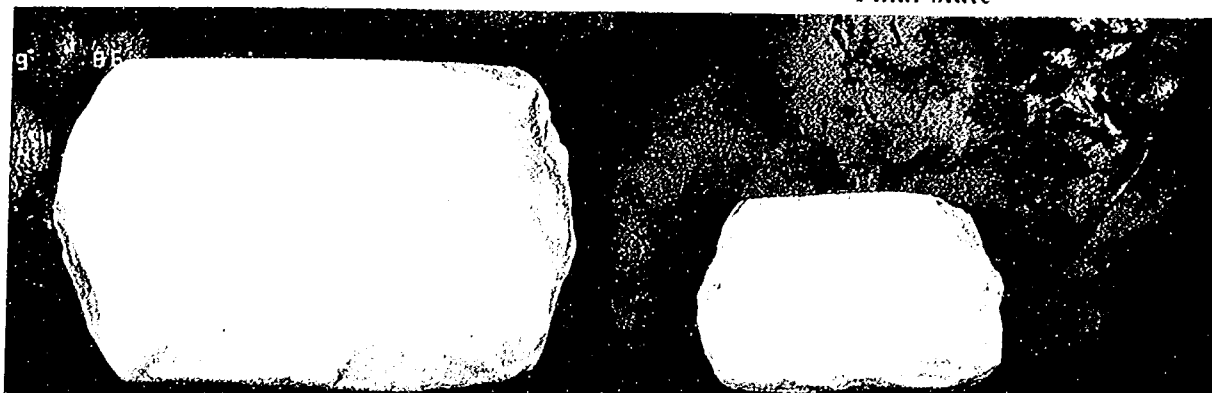


Plate 10 Initial and final states of sample No.10 for the different durability tests.

Initial state

Final state



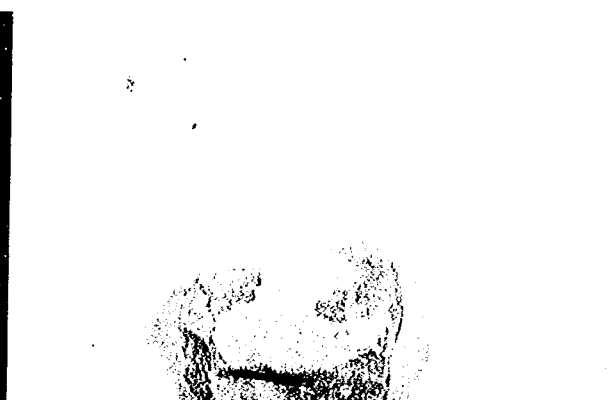
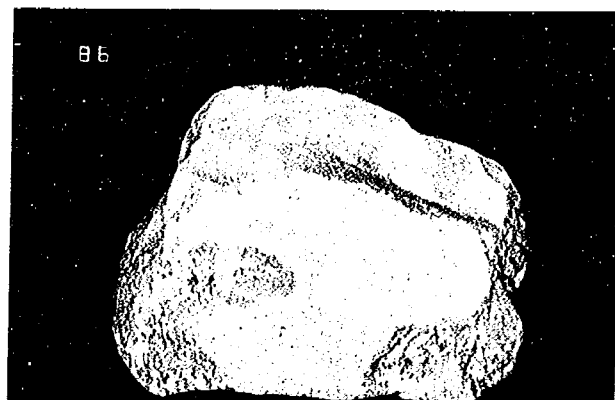
Sample No. 1

Sample No. 10-1



Sample No. 1

Sample No. 10-2



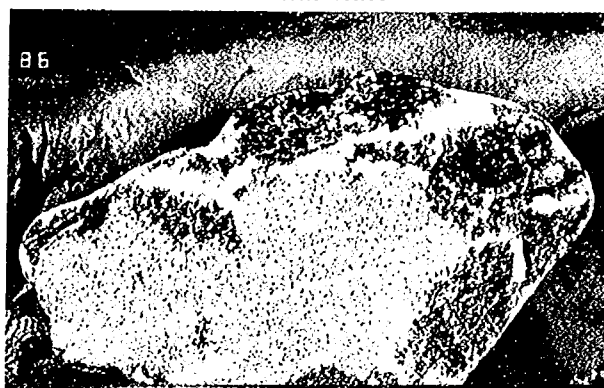
Sample No. 10

Sample No. 10-3

Plate 11 Initial and final states of sample No.11 for the different durability tests.

Initial state

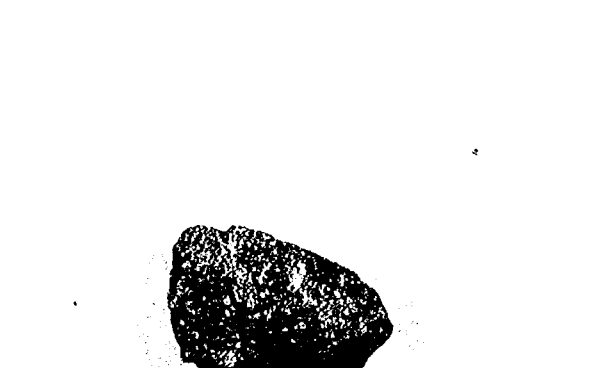
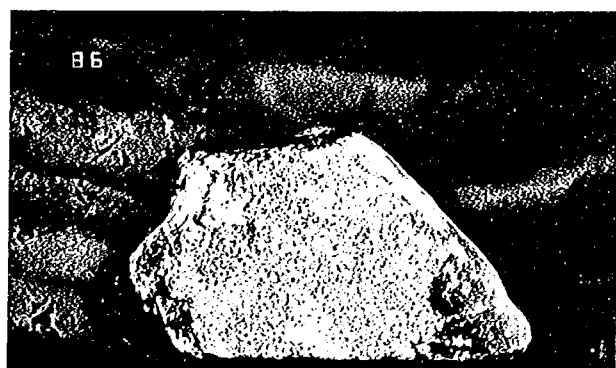
Final state



Sample No. 11-1



Sample No. 11-2

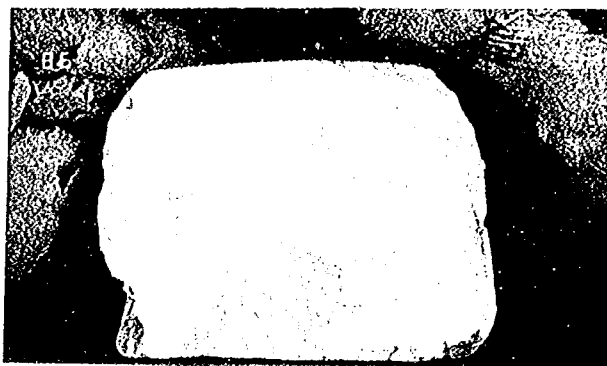


Sample No. 11-3

Plate 12 Initial and final states of sample No.12 for the different durability tests.

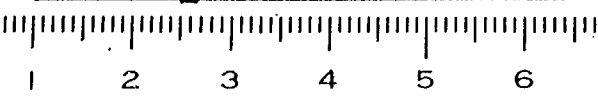
Initial state

Final state



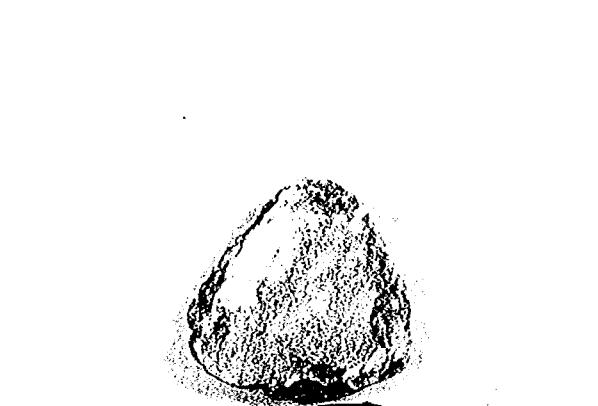
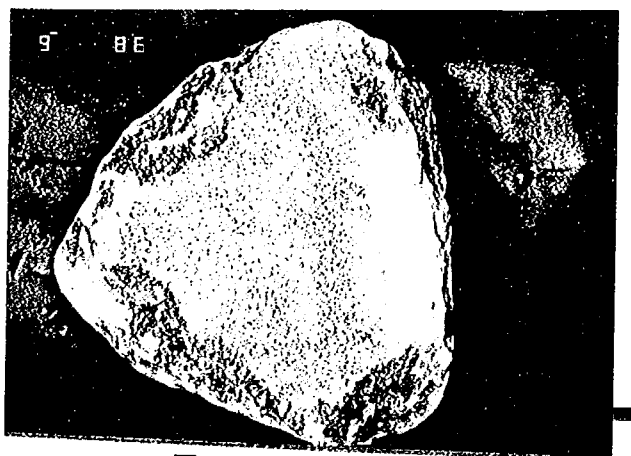
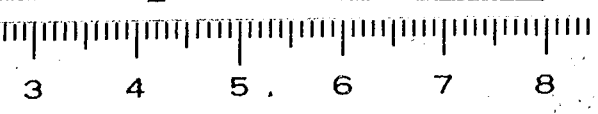
Sample No. 12

Sample No. 12-1



Sample No. 12-2

Sample No. 12



Sample No. 12-3

Sample No. 12

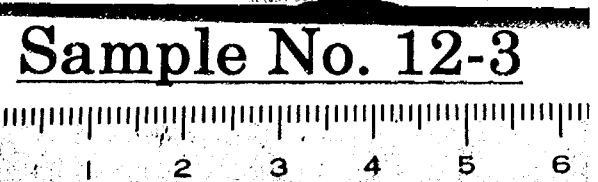
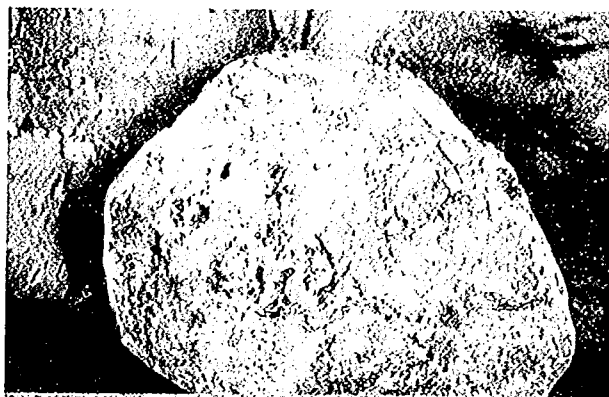


Plate 13 Initial and final states of sample No.13 for the different durability tests.

Initial state

Final state



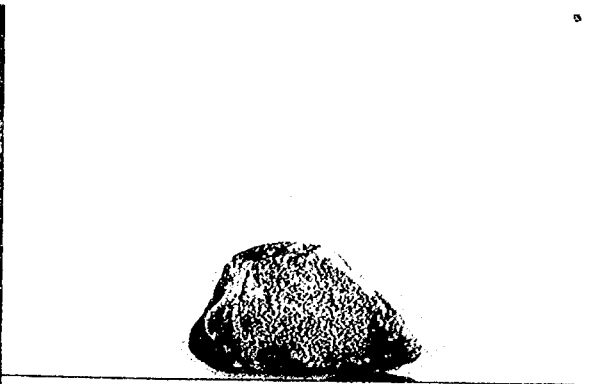
Sample No. 13-1

Sample No. 13-1



Sample No. 13-2

Sample No. 13-2

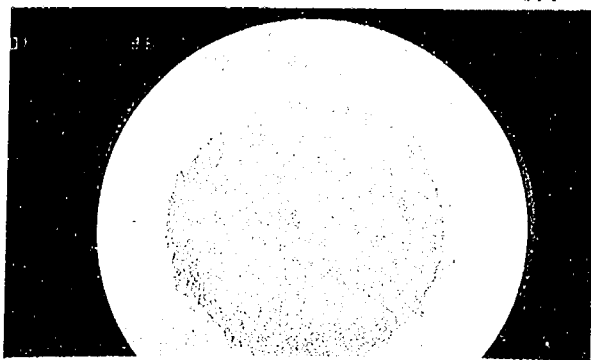


Sample No. 13-3

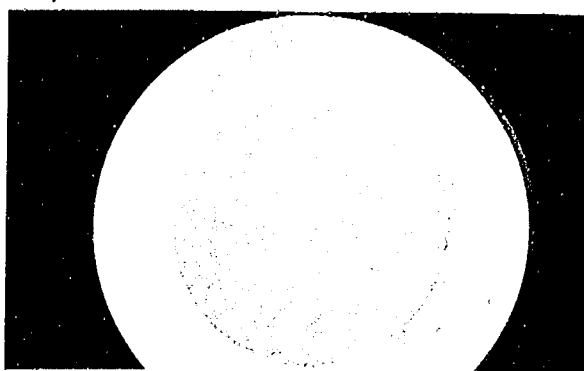
Sample No. 13-3



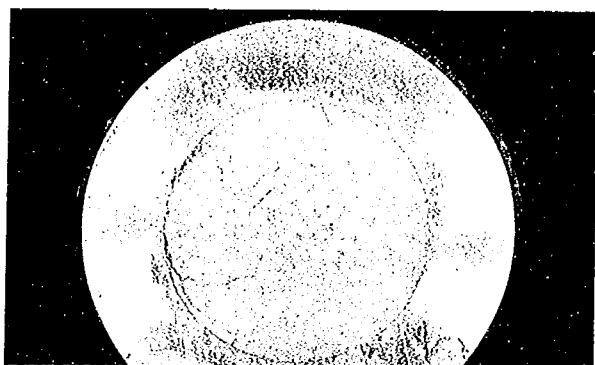
Plate 14-a Final weathered products of studied samples after acidic durability test.
(Egyptian samples)



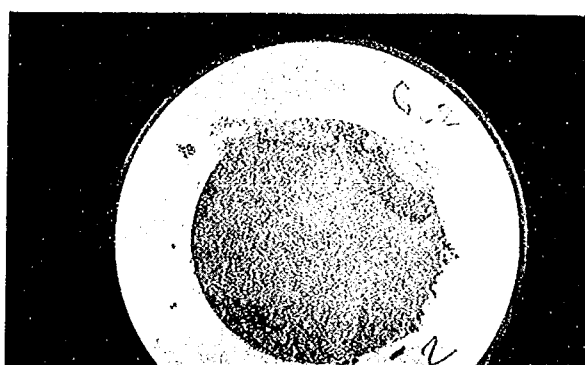
Sample No. 1-2



Sample No. 5-2



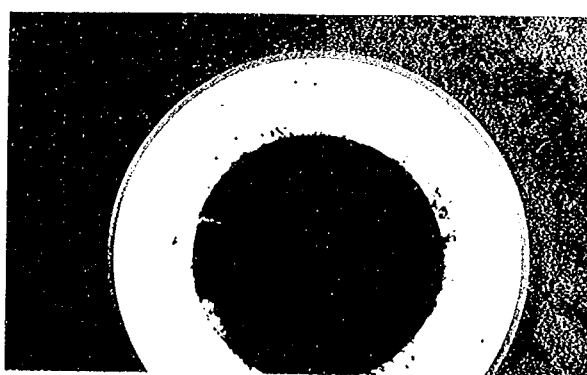
Sample No. 2-2



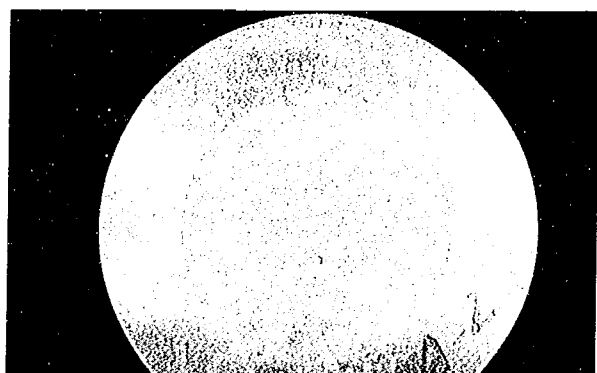
Sample No. 6-2



Sample No. 3-2



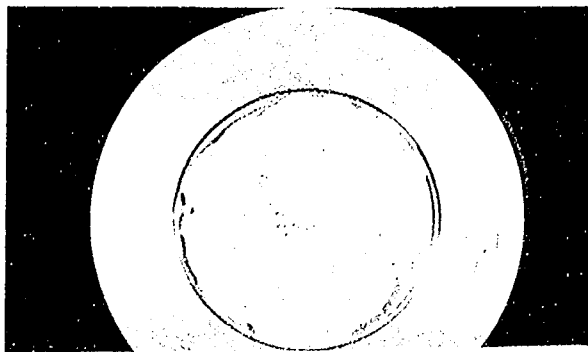
Sample No. 7-2



Sample No. 4-2

Plate 14-b Final weathered products of studied samples after acidic durability test.

(Japanese samples)



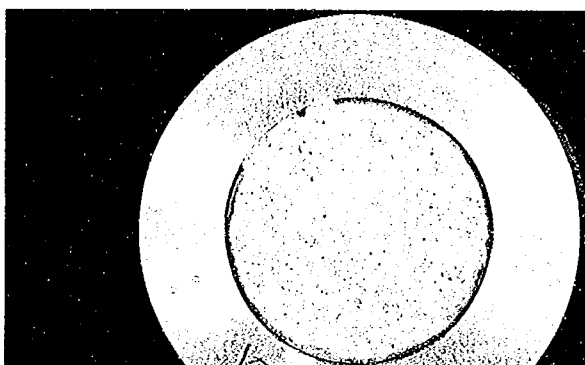
Sample No. 8-2



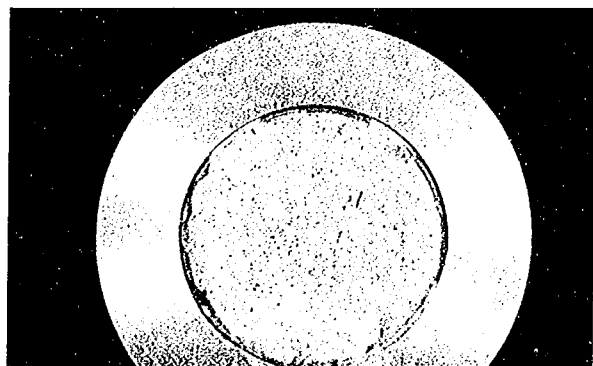
Sample No. 11-2



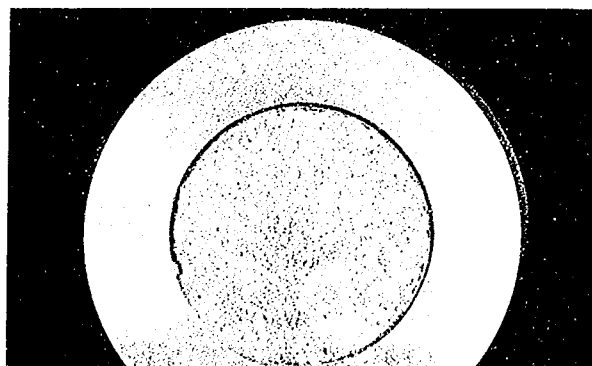
Sample No. 9-2



Sample No. 12-2



Sample No. 10-2



Sample No. 13-2

Plate 15 Thin section photomicrographs of the intact sample No.1

Scale:  200 μ m

Open Nicol

Cross Nicol

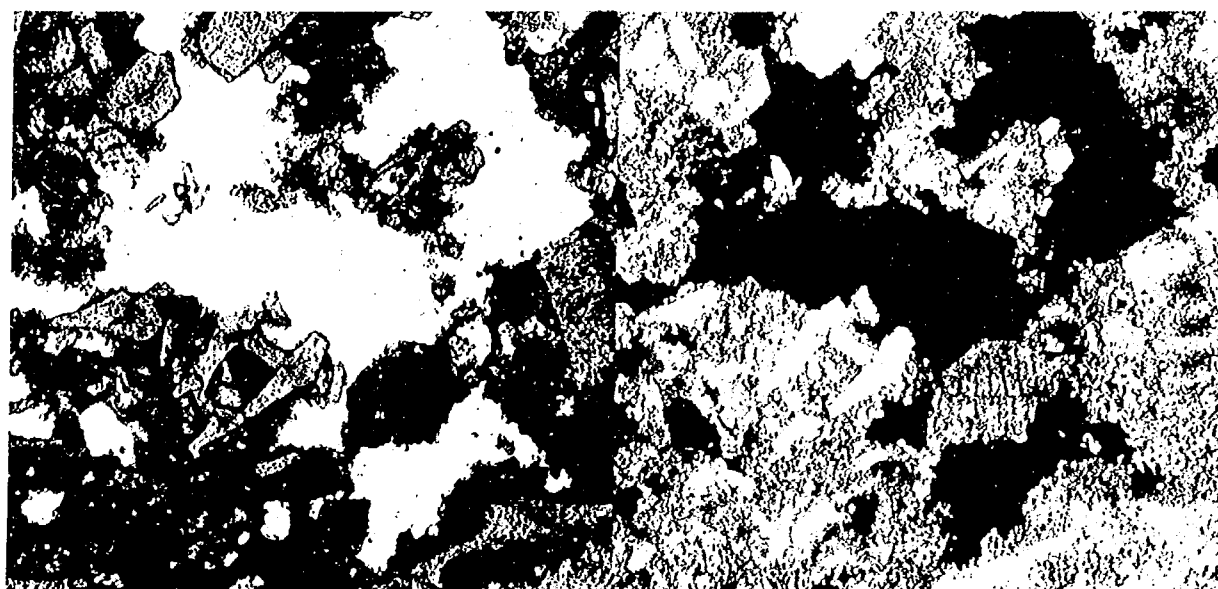
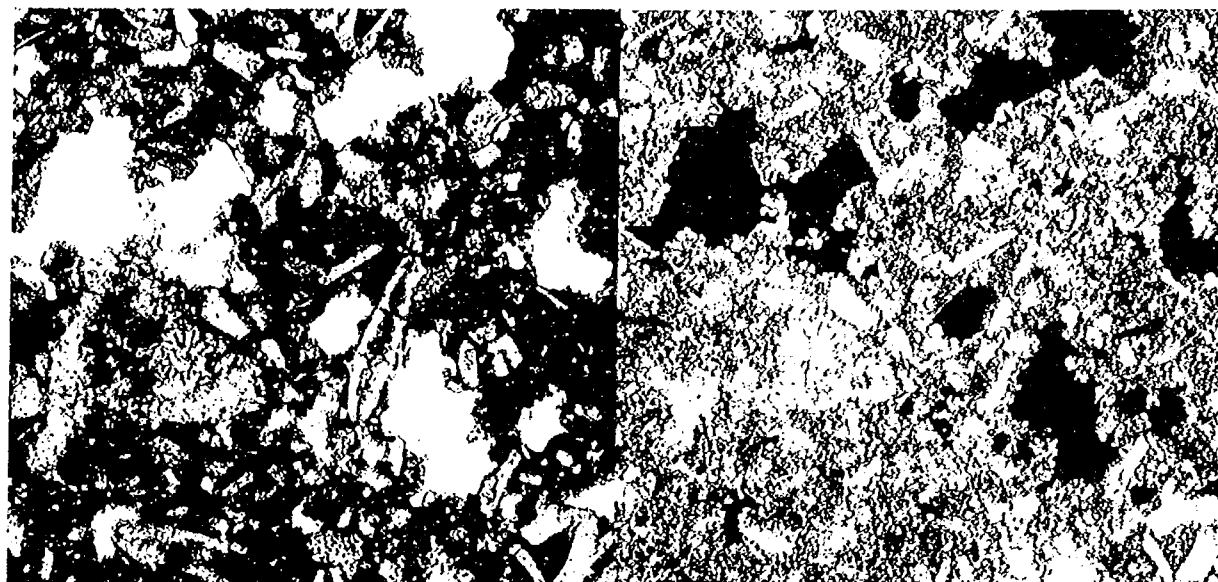
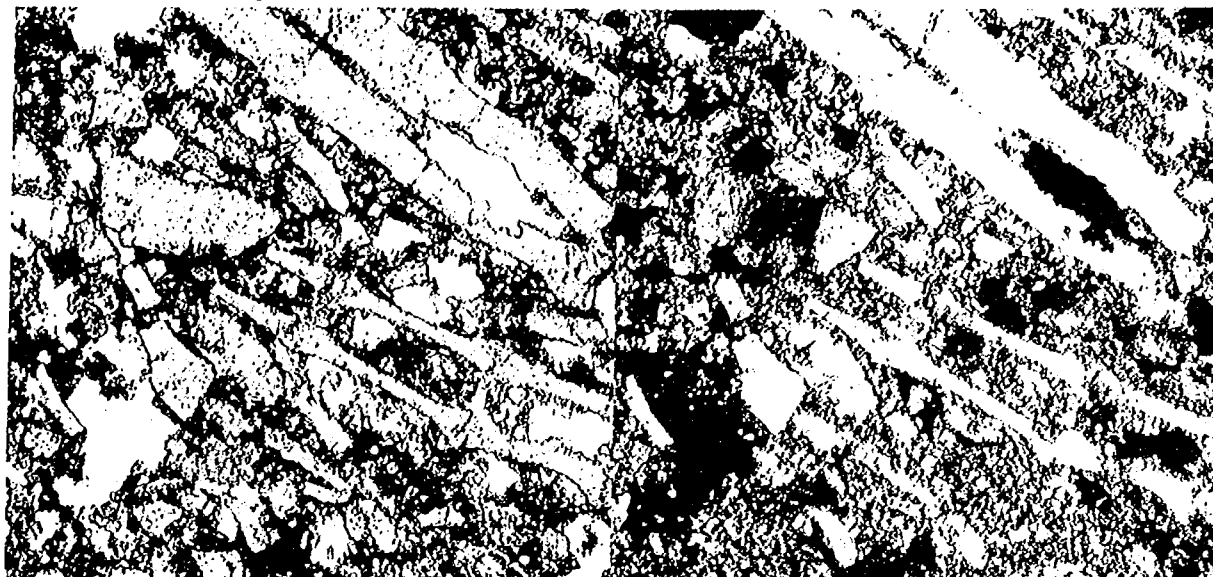


Plate 16 Thin section photomicrographs of the intact sample No.2

Scale:  200 μ m

Open Nicol

Cross Nicol

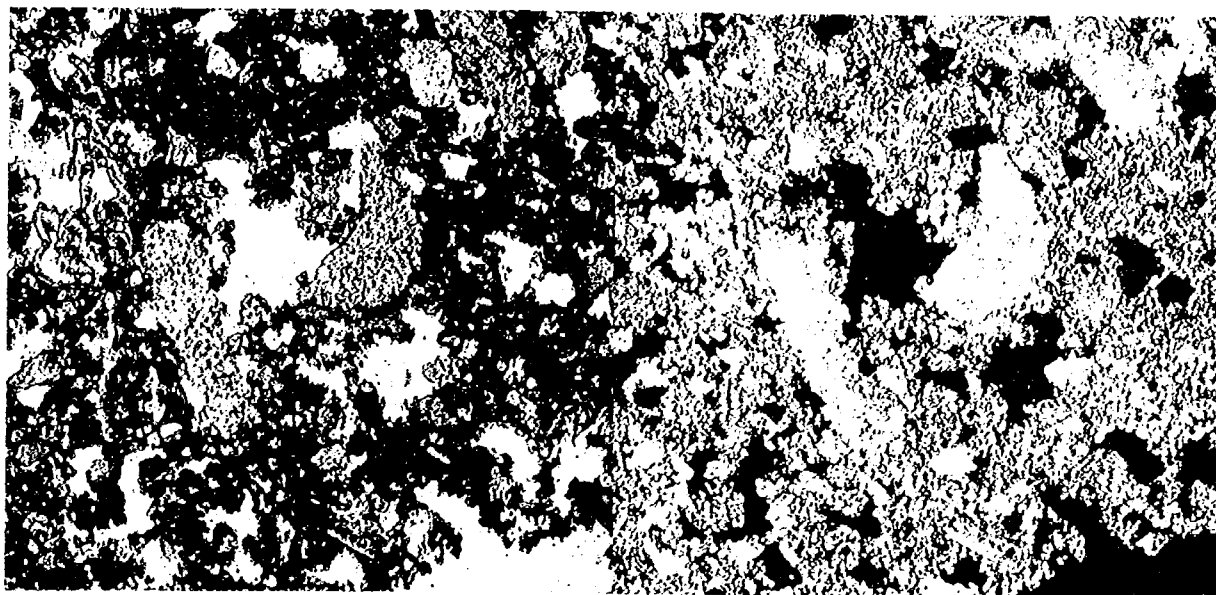
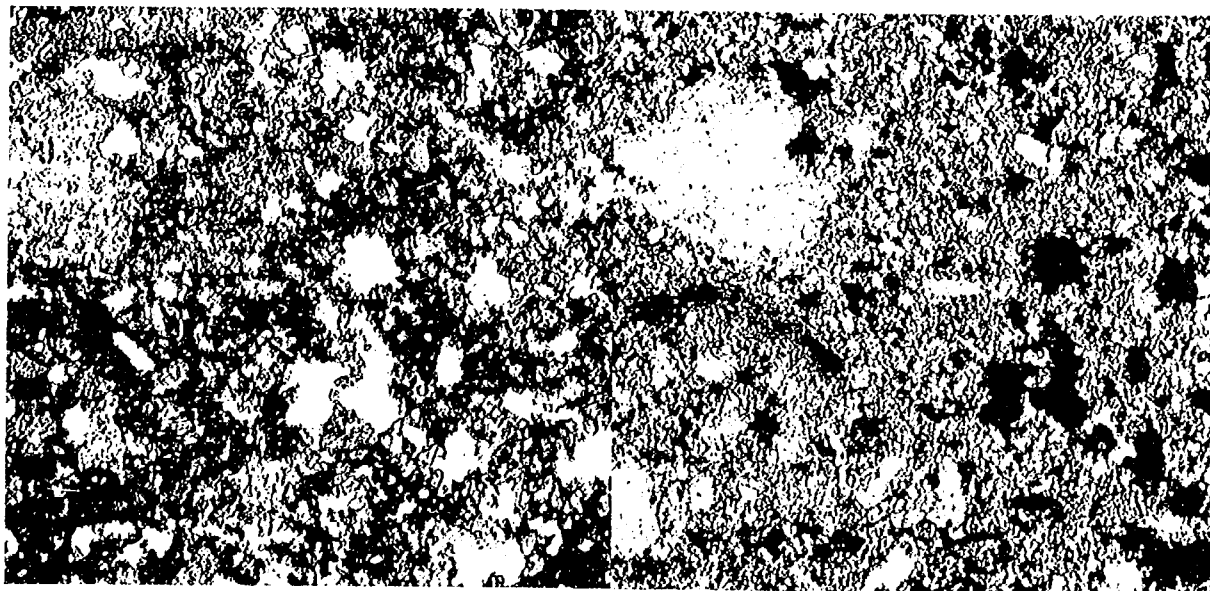
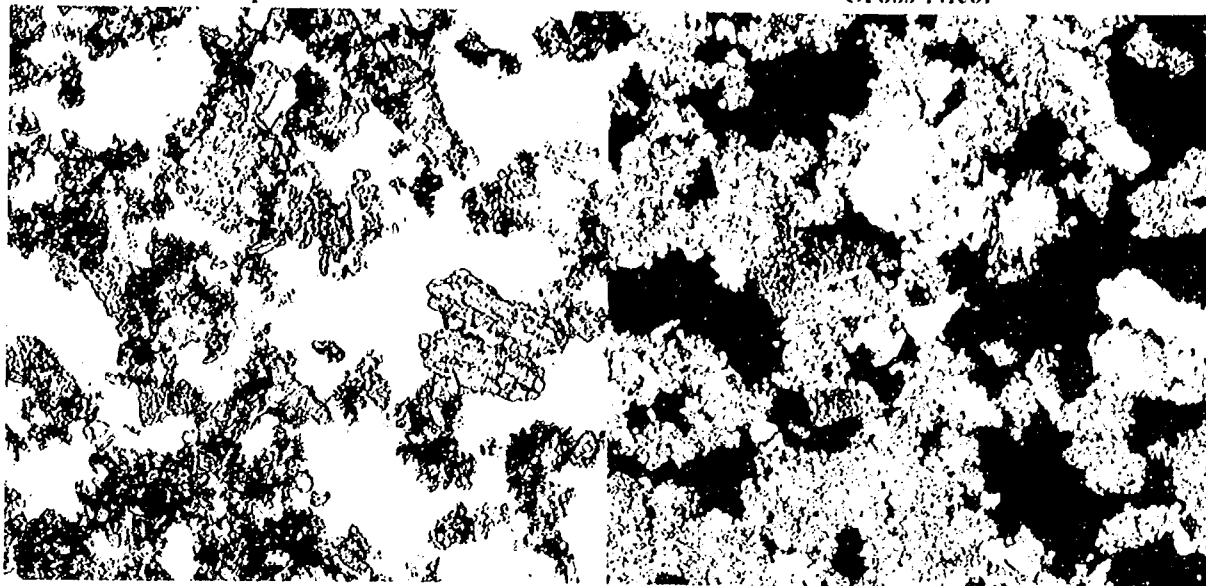


Plate 17 Thin section photomicrographs of the intact sample No.3

Scale:  200 μ m

Open Nicol

Cross Nicol

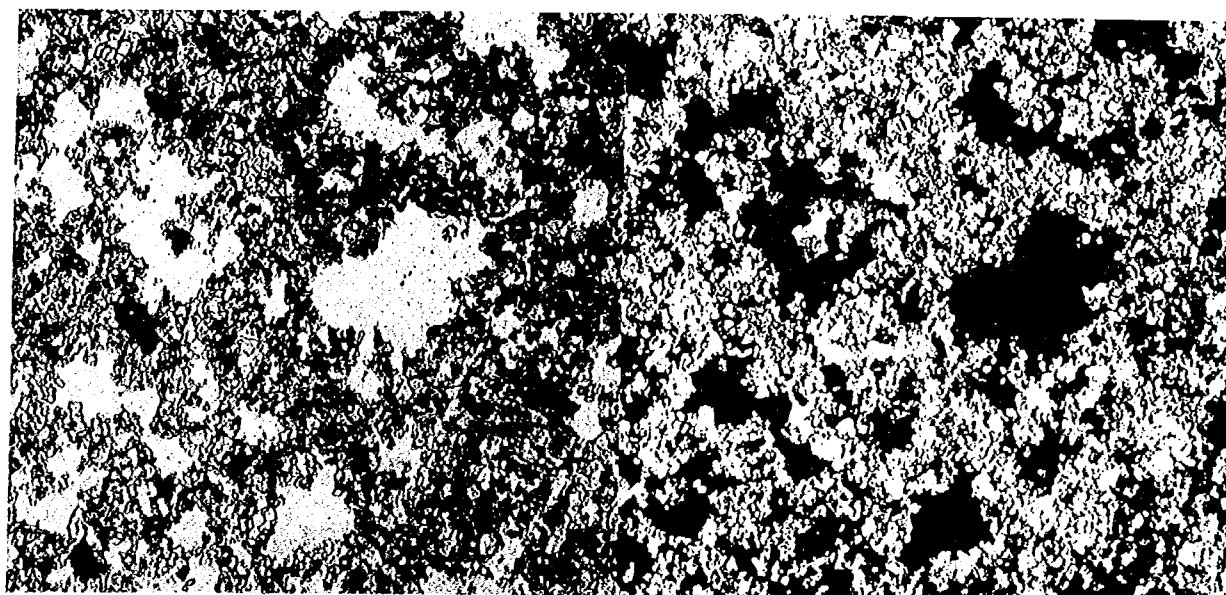
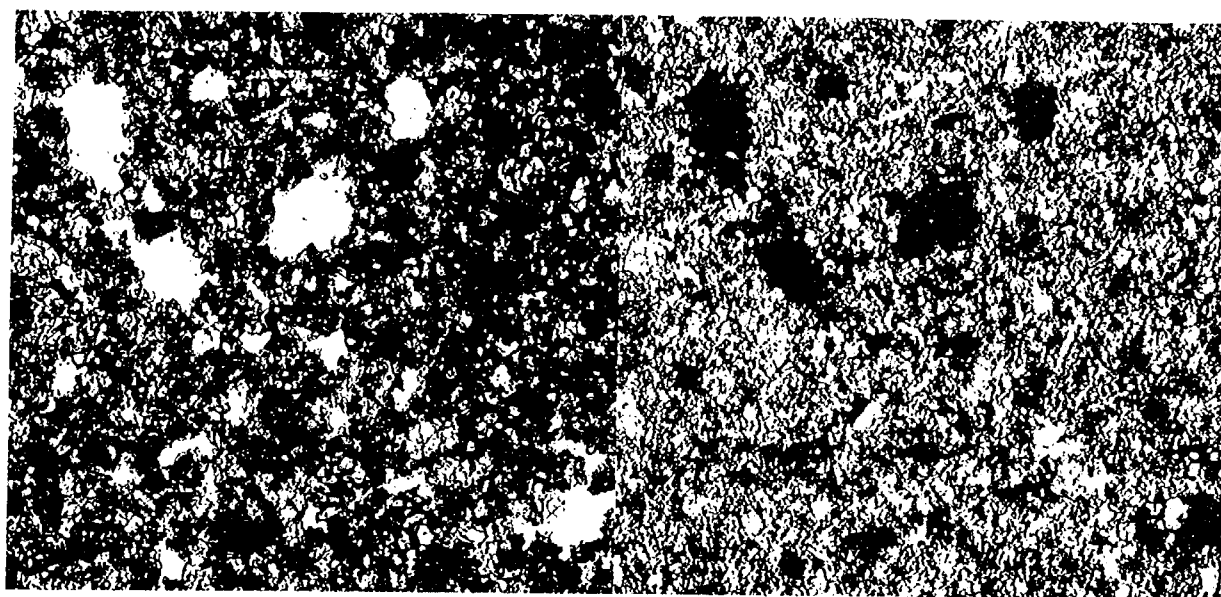
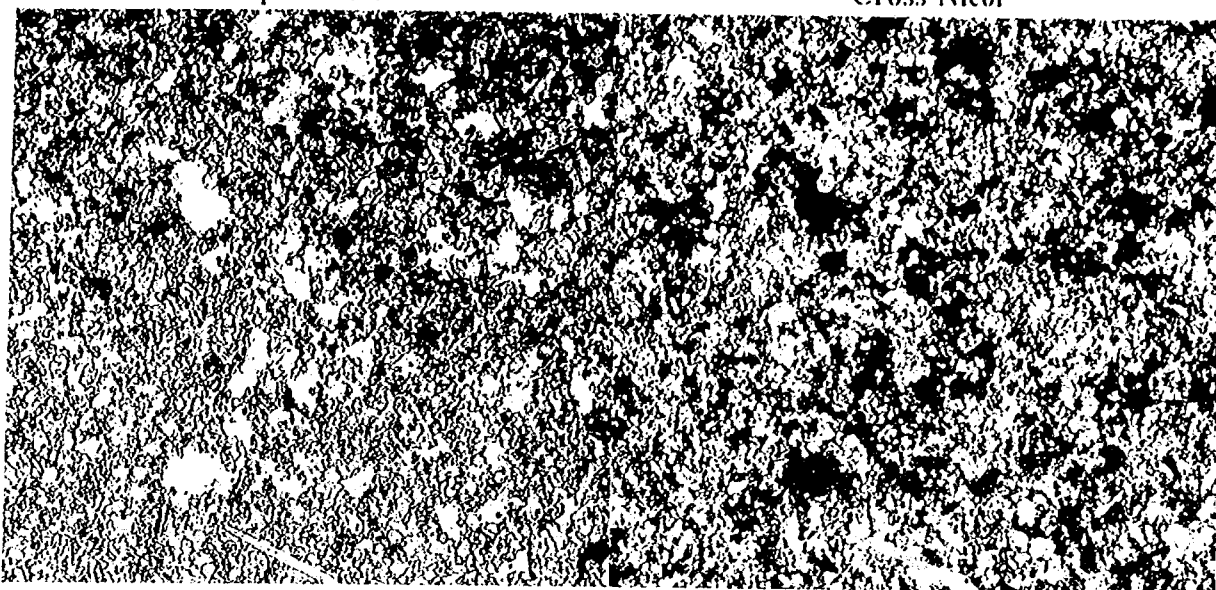


Plate 18 Thin section photomicrographs of the intact sample No.4

Scale:  200 μ m

Open Nicol

Cross Nicol

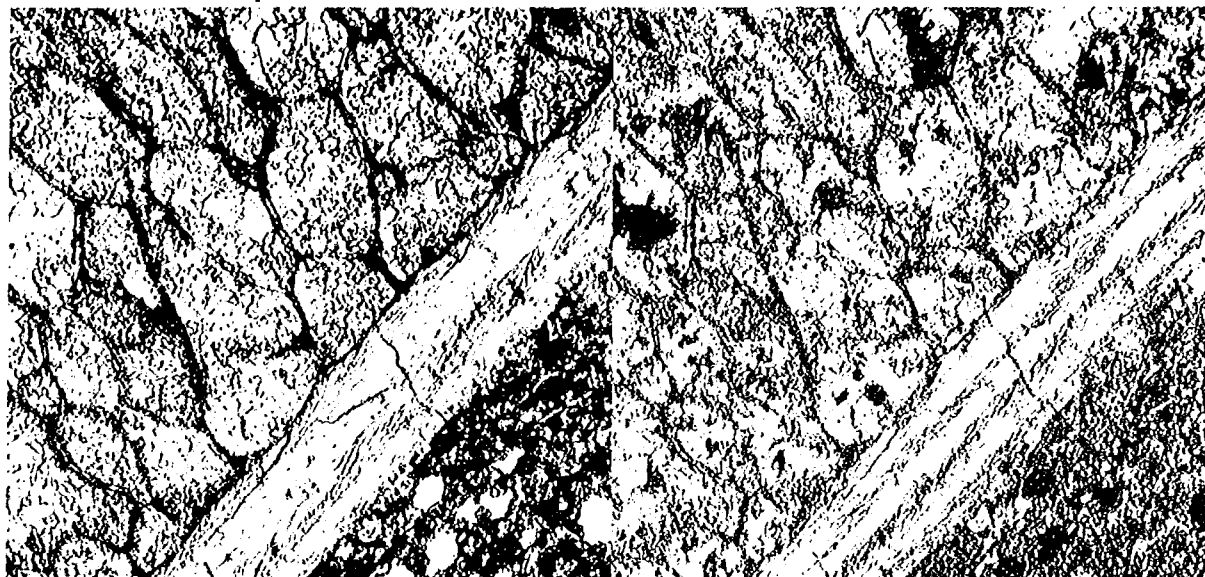


Plate 19 Thin section photomicrographs of the intact sample No.5

Scale:  200 μ m

Open Nicol

Cross Nicol

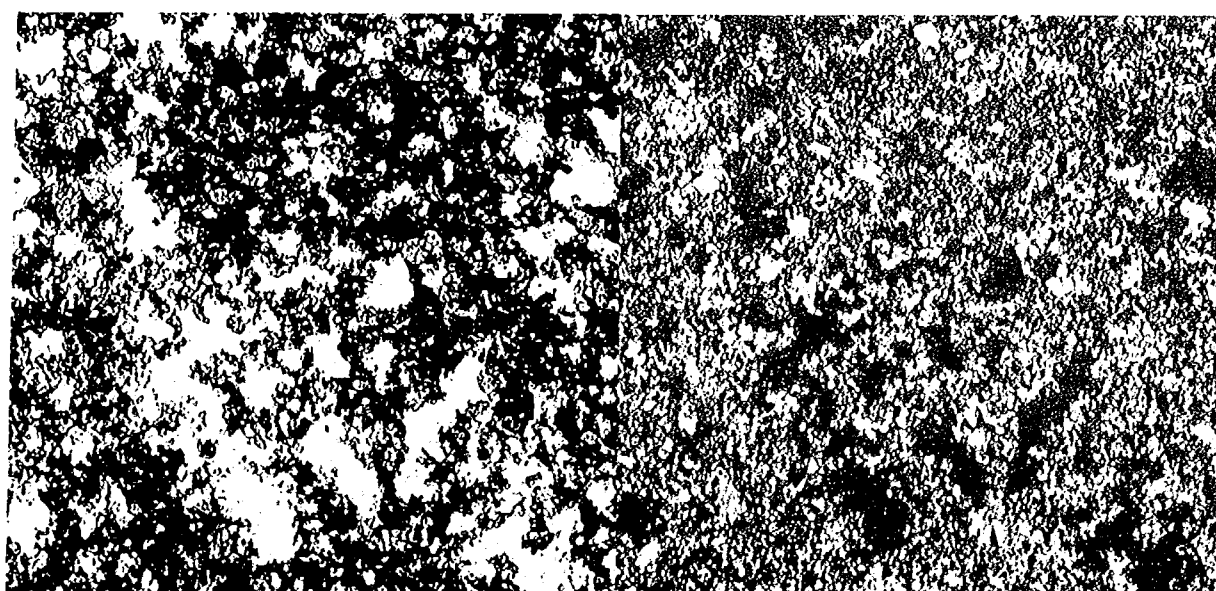
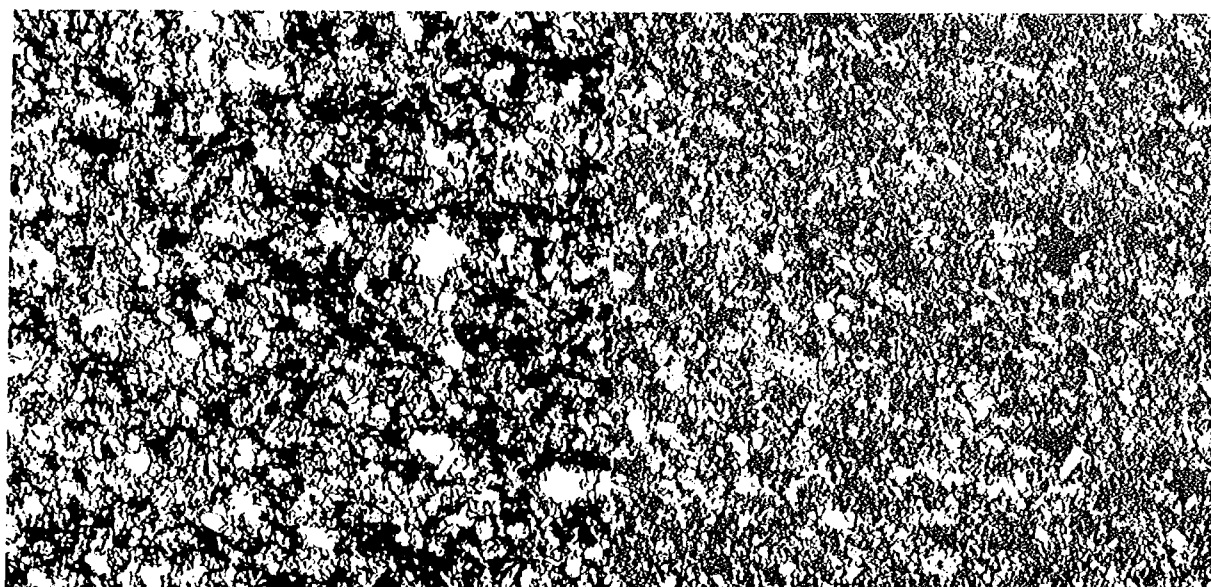
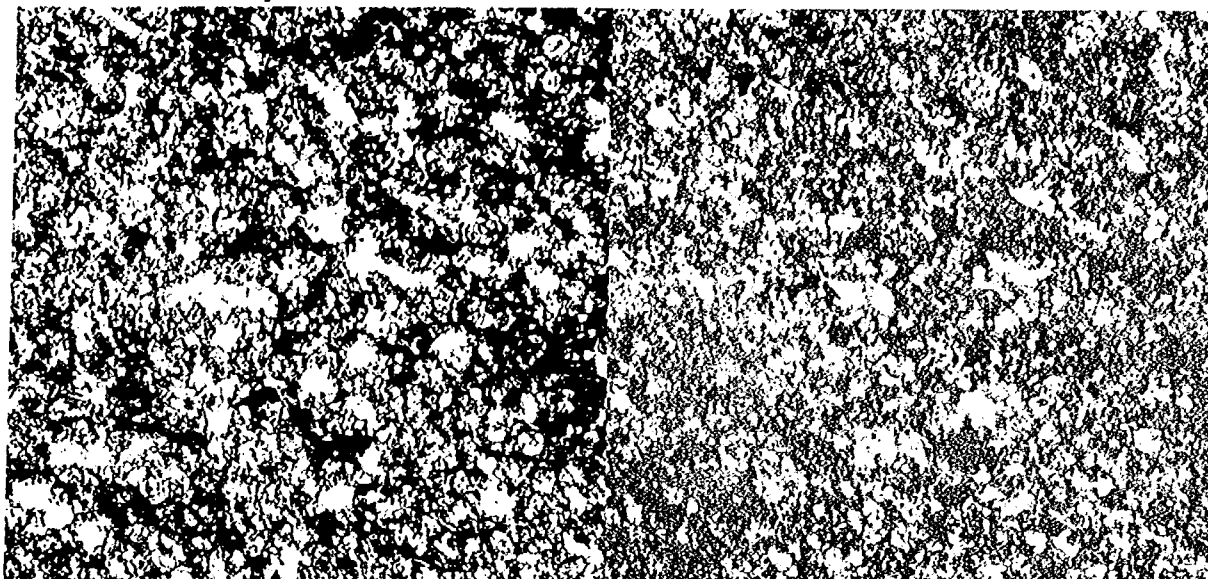


Plate 20 Thin section photomicrographs of the intact sample No.6

Scale:  200 μ m

Open Nicol

Cross Nicol

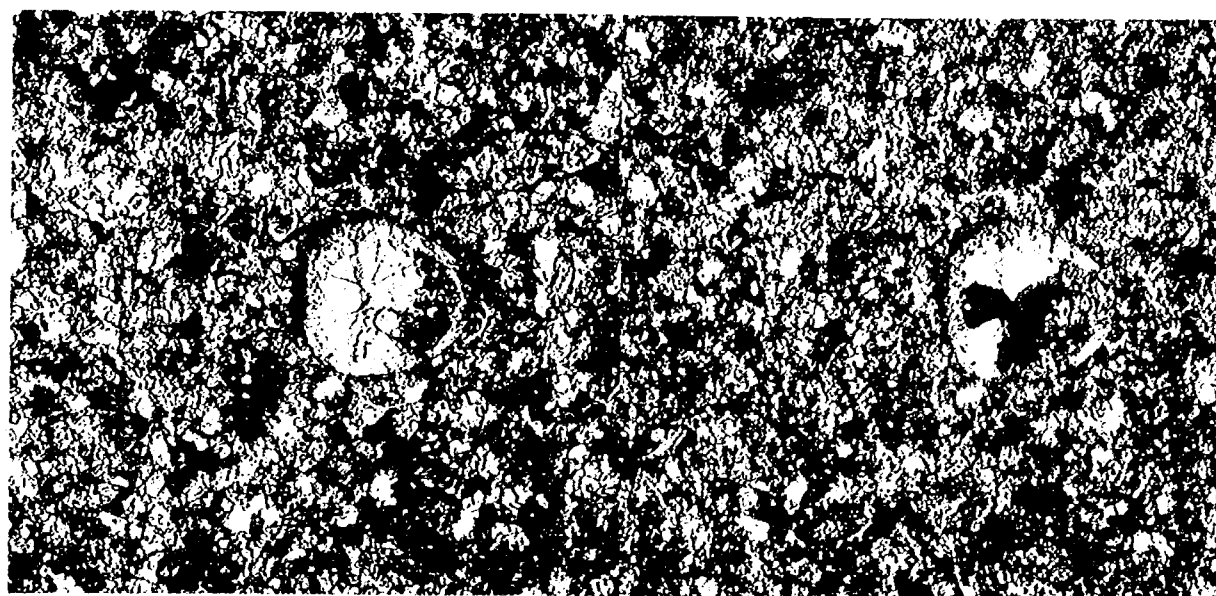
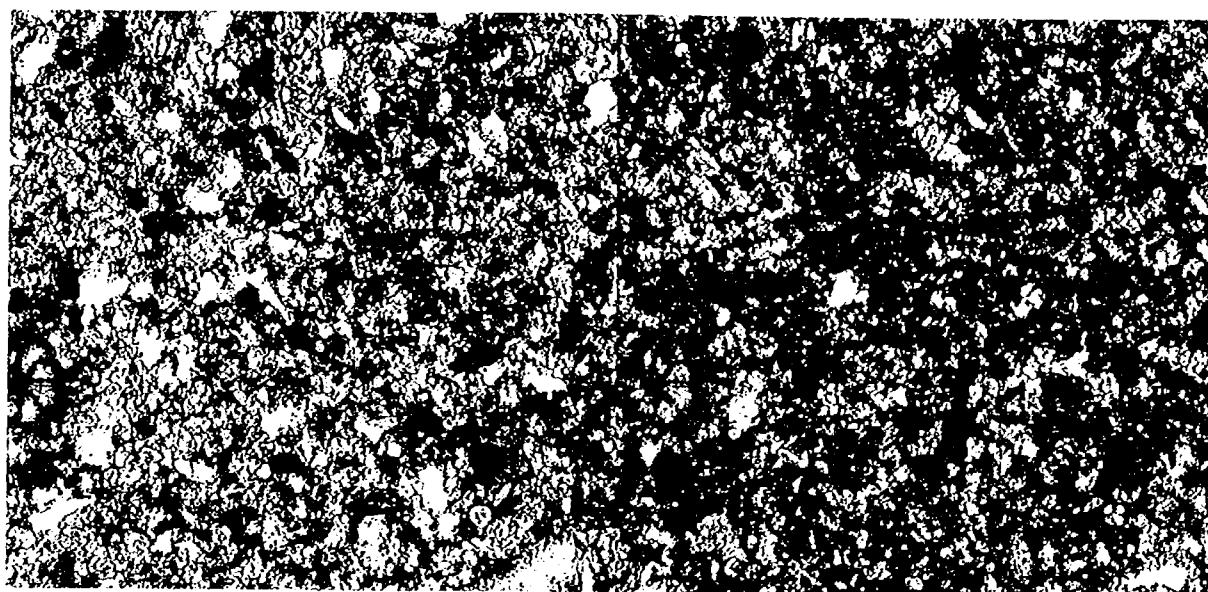
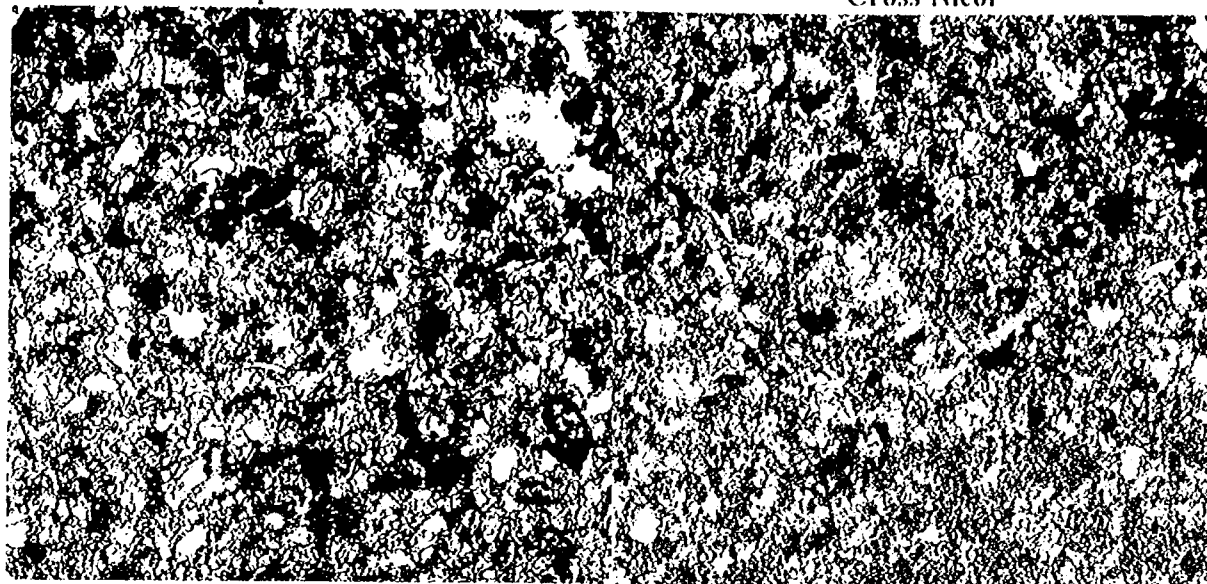


Plate 21 Thin section photomicrographs of the intact sample No.7

Scale:  200 μ m

Open Nicol

Cross Nicol

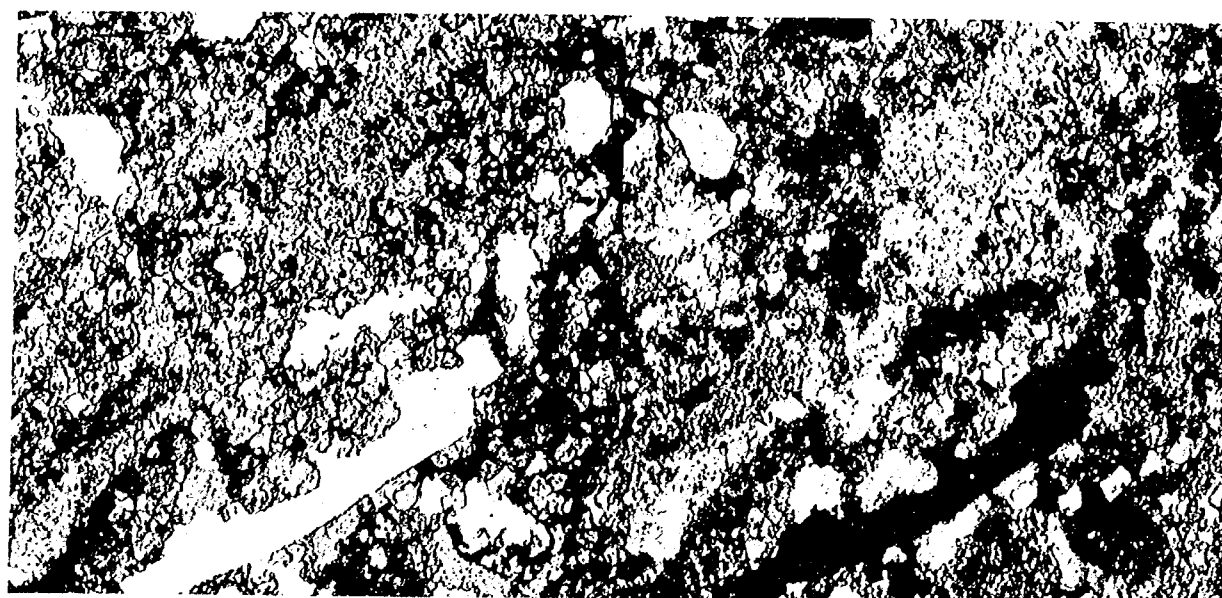
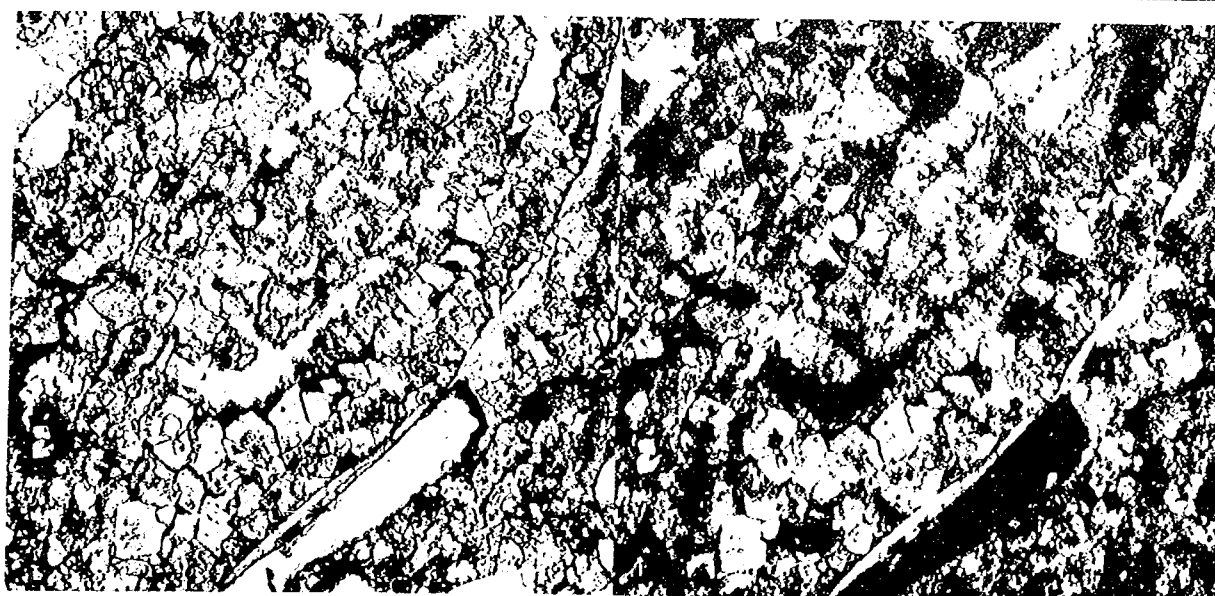
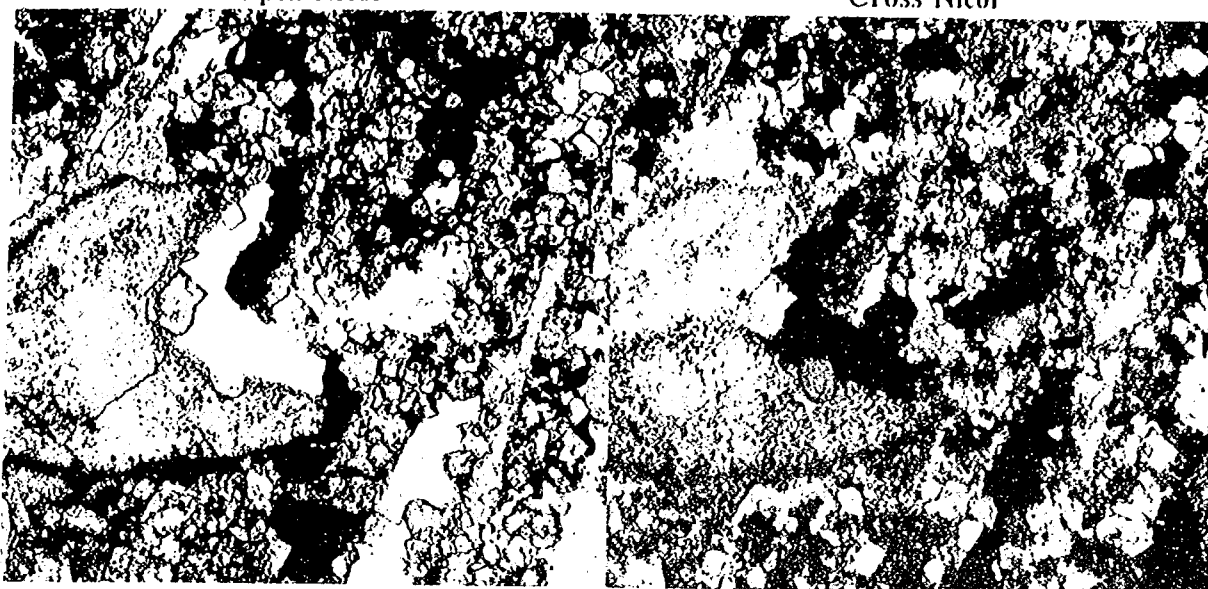


Plate 22 Thin section photomicrographs of the intact sample No.8

Scale:  200 μ m

Open Nicol

Cross Nicol

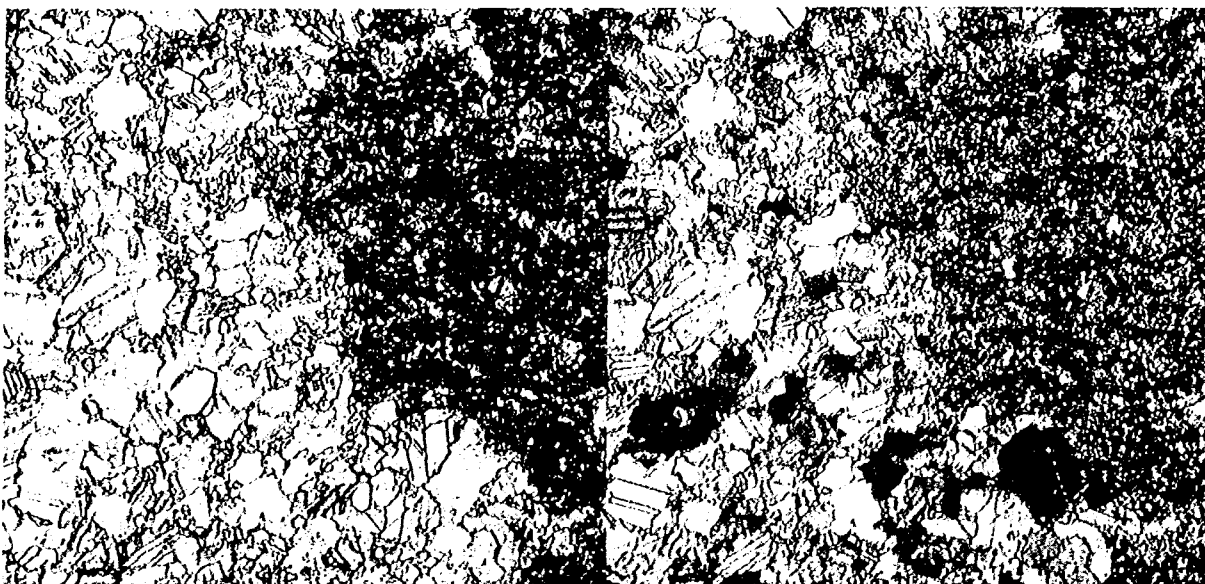


Plate 23 Thin section photomicrographs of the intact sample No.9

Scale:  200 μ m

Open Nicol

Cross Nicol

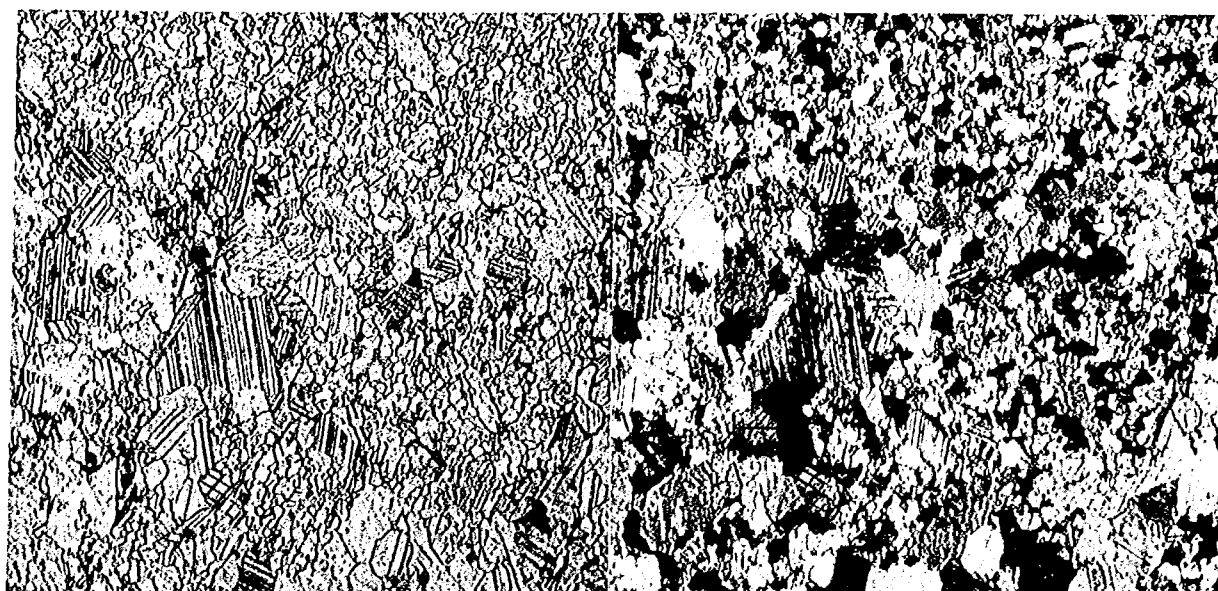
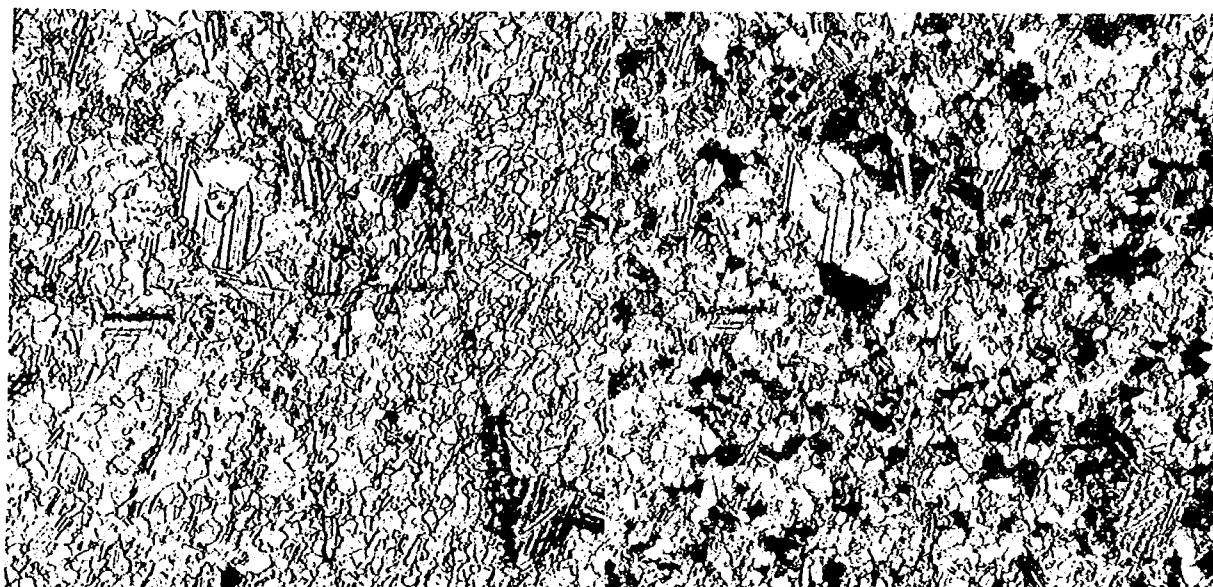


Plate 24 Thin section photomicrographs of the intact sample No.10

Scale:  200 μ m

Open Nicol

Cross Nicol

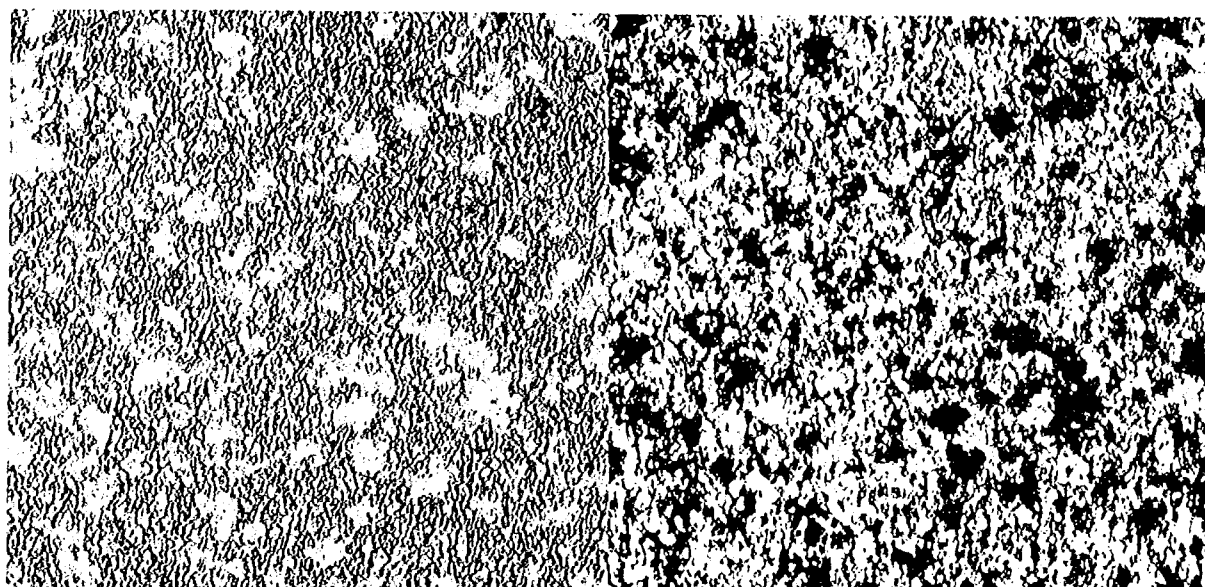


Plate 25 Thin section photomicrographs of the intact sample No.11

Scale:  200 μ m

Open Nicol

Cross Nicol

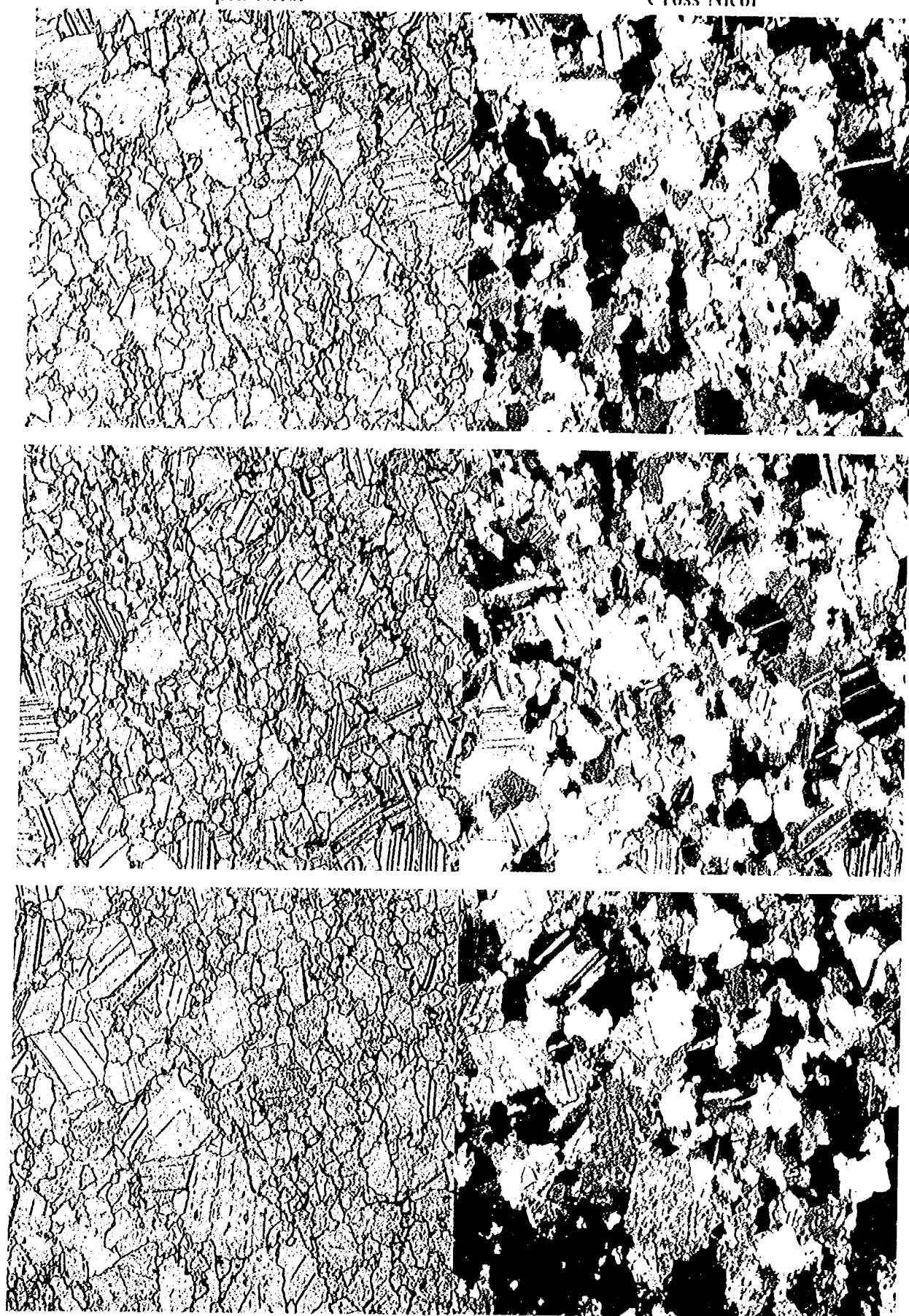


Plate 26 Thin section photomicrographs of the intact sample No.12

Scale:  200 μ m

Open Nicol

Cross Nicol

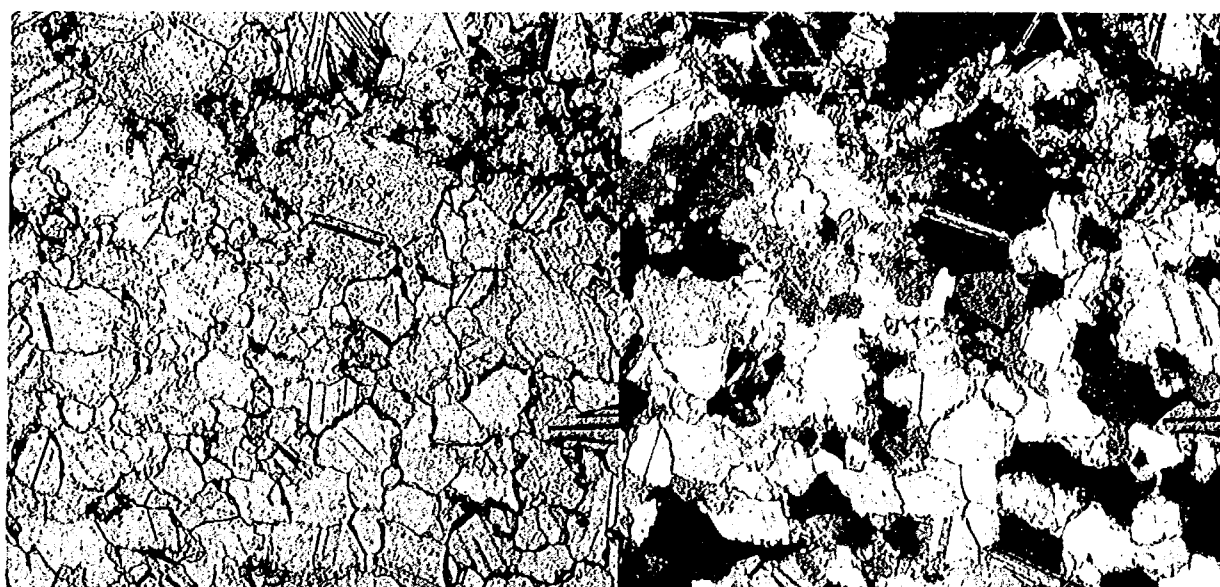
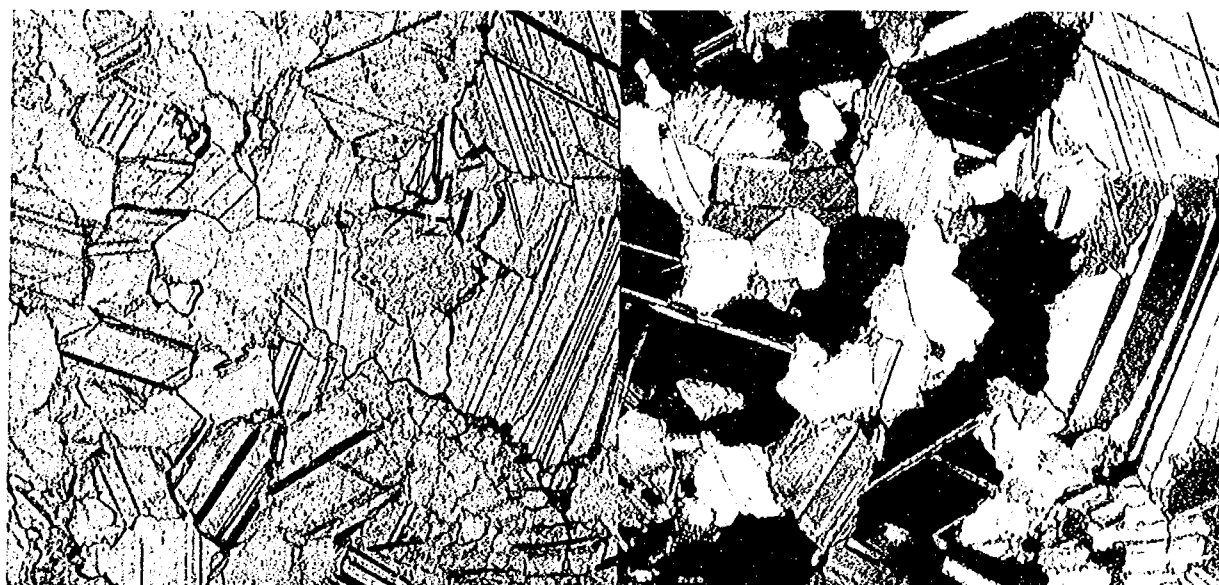
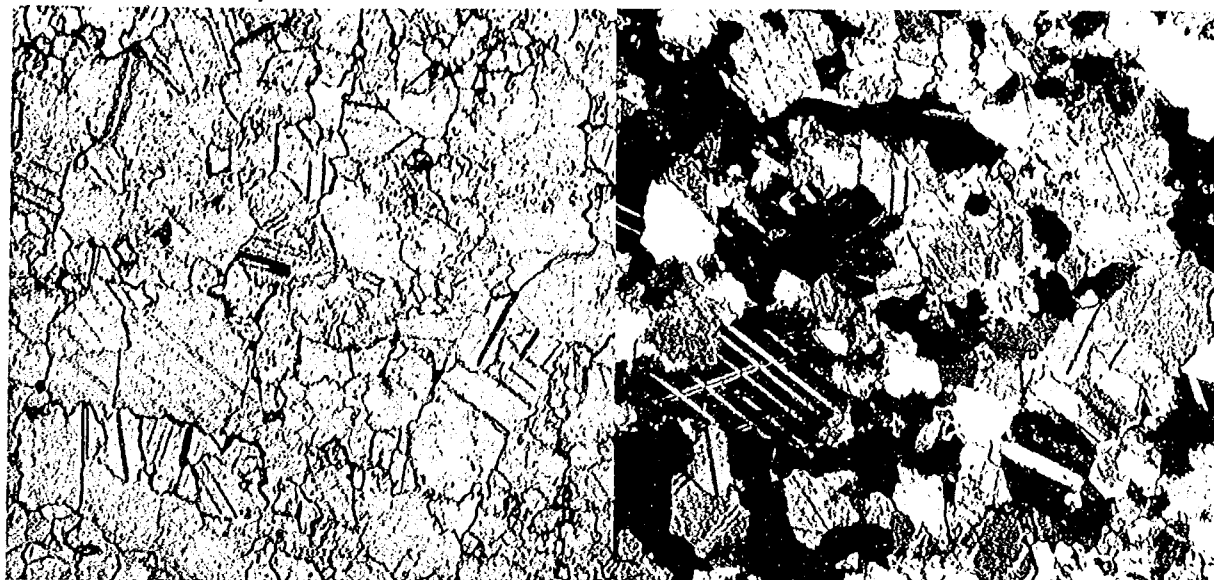


Plate 27 Thin section photomicrographs of the intact sample No.13

Scale:  200 μ m

Open Nicol

Cross Nicol

