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Productivity Investigation of Chemical Filling-Reinforced Methods Applied to Different Marbles from Eastern and Southeastern Anatolia Region of Turkey

M. AYHAN[1,*] and F. GÖKDEMIR[2]

[1]Department of Mining Engineering, Dicle University, 21280 Diyarbakir, Turkey
[2]Dimer Marble Company, Diyarbakir, Turkey

*Corresponding author: Fax: +90 412 2488405; Tel: +90 412 2488403; E-mail: mayhan@dicle.edu.tr

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In this study, particularly the plates and strips of crackle, porous and spongy Elazig-Visne, Sand Wave and Brown Espera produced in Eastern and Southeastern Anatolia region of Turkey were filled-reinforced by applying epoxy resin, ultraviolet resin and fiber mesh. Then, considering the breaking rate on polishing line, filling-reinforcing cost and sales prices of the said marbles, a cost analysis is performed and the economic income is calculated. Filling reinforcing studies showed that breaks which occurred during polish was largely prevented and a significant amount of economic income was gained.

Key Words: Plate-strip, Filling-reinforcing performance, Epoxy-ultraviolet resin, Fiber mesh, Cost analysis.

INTRODUCTION

Today marbles are widely used in construction industry, interior and exterior coatings of buildings, interior floorings, staircases and entrance parts as well as kitchens and bathrooms, outdoors such as gravestones and monuments.

It is possible to summarize the geological unconformities of the masses by items as; micro-fissures, fissures, cracks, faults, folds, bedding planes and shistosity and foliation planes[1]. With the technological developments and growing competition experienced in marble industry in recent years, marble products began to be widely used in thinner and larger forms. But the need for filling-reinforcement has emerged in order to produce natural stones with faults and defects in such qualities. Developments experienced in filling-reinforcement field allowed operation of previously non-produced and left marble areas. Nevertheless, this enables the marbles with structural defects and faults to be sold with higher prices by significantly reducing the losses during the cutting and processing of marbles and adding them aesthetics.

Wastages up to 40-50 % occur during cutting and processing of some marbles. Major part of the breaks on marble plates occur during cutting and some during their transfers[2].

Crackle marbles have led to failure in marketing due to endurance problems. Thinner plates must be produced in order to reduce shipping costs. Prices of solid plates must be increased particularly due to losses in plates with large amounts. Damaged blocks in the inventories of quarries which are widely demanded in the market and have limited reserves were rapidly increased[3]. Epoxy resins reduce breakage ratio because of their deep penetration into cracks. However, ultraviolet resins are better than other filling methods due to the acceleration of the production period when the production period is considered[4].

In this study, the effects of the chemical filling-reinforcing applications performed on Brown Espera-Adiyaman, Sand Wave-Diyarbakir and Elazig-Visne marble plates produced in Eastern and Southeastern Anatolia region of Turkey and strips on the cutting and processing performance through cost analysis studies performed in marble processing plants and spreading over a long period.

EXPERIMENTAL

Although several variables exist affecting the choice of reinforcing or filling process on natural stones, the two most important factors are the problem type of the marble, application method or the characteristic of the filling material. If the material has capillary cracks and high breaking rate, epoxy resins with high liquidity are used. But if the breaking rate is not very high, they have a porous structure and it is required to minimize the manipulation period, UV resins are preferred. In many times, depending on the problem type of the marble, several filling-reinforcing methods can be applied together[2,3].

Epoxy resins: Epoxy resins are polymer-forming systems containing two principal components that interact to produce highly cross-linked products with exceptional toughness, adhesion and chemical resistance[5]. Epoxies consist of materials accelerating freezing which are defined resins and catalysts as main material. These two materials are applied by mixing with each other in certain ratios. Mixing ratios vary depending on the conditions in application[6].

Since the freezing period of epoxy resins differ depending on the temperature and humidity of the environment of application, manufacturers produce epoxy resins which can be cured in different periods for different temperatures[7]. While epoxy and meshing is concurrently applied on cut-rock plates requiring reinforcement in general, additives are used on strips and faience together with meshing and epoxy.

Ultraviolet resin: Ultraviolet resins are polyester based and generally single component polymers with changing mechanical and chemical structures as the result of reaction under luminous energy[8].

Average drying periods of 1-2 h required for the manipulation of traditional resins are zeroed with UV resins. UV resin forms a thin film layer on the surface by being cured under UV lamps, immediately gets polymerized under the effect of the rays and stiffens losing its viscosity. UV resins are used in reinforcing surfaces of plates with shallow holes, capillary cracks and plenty of pores[9]. The cement, mastic, polyester and epoxy filling materials used in the present study have generally improved the physical and mechanical properties of the studied travertine at different rates. A better performance was achieved in the epoxy-filling applications than with the other filling materials tested[10].

There is a new method which improved for the consolidation of slabs in an autoclave with the use of vacuum and positive pressures; can consolidate 60 slabs and more with one operation only. The result is outstanding both under the structural and aesthetic aspect because the process introduces the resin in every crack and flaw of the slab, going through its entire thickness[11].

Due to high level of wastage occurring in polishing phase, filling-reinforcing is applied on plates-strips produced from Elazig-Visne marbles manufactured in Elazig region. Brown-Espera marbles manufactured in Adiyaman region and Sand-Wave marbles manufactured in Diyarbakir region which all have a significant place in the international market.

Plate-strip reinforcement experimental studies are performed in Dimer A.S. Marbles Processing Plant with a production capacity of nearly 1,000,000 m^2 plate and strip yearly and which operates in Diyarbakir Organized Industrial Zone. The physical, chemical and mechanical characteristic of Elazig-Visne, Brown-Espera and Sand-Wave marbles are given in Table-1.

In evitable breaks occur during cutting and processing due to the anisotropic and heterogeneous structure of the marbles. The plates and strips of the said marbles requiring filling-reinforcing have problems such as cracks, veins, pores and holes. Percentage of wastage in Elazig Visne plates and strips containing this type of problems can reach at 60 % and in Brown Espera at 50 %.

Elazig Visne: It is occurred by cementing faults and cracks of the ophiolitic material, using calcite filling. This breche marble is called scientifically as ophicalcite. Calcites don't fairly fill the cracks or instead the clay fills these cracks on those blocks and slabs produced from these marbles and consequently cracks-wastages occur during cutting process.

TABLE-1
PHYSICAL, CHEMICAL AND MECHANICAL CHARECTERISTICS SAND WAVE, ELAZIG CHERRY AND BROWN ESPERA [Ref. 1,12,13]

Parameters	Sand Wave	Elazig Cherry	Brown Espera
Hardness (mohs)	3.24	3.5	3-3.50
Unit volume weight (g/cm^3)	2.67	2.71	2.73
Uniaxial compressive strength (kgf/cm^2)	722.9	945	1397
Porosity (%)	1.30	1.86	1.40
Fullness ratio (%)	99.5	98.63	99.57
SiO_2 (%)	0.38	19.60	0.50
Fe_2O_3 (%)	0.08	7.41	0.20
MgO (%)	0.36	14.85	1.25
CaO (%)	55.04	29.93	51.60

Sand wave: considering these marbles in the group of stilolitized limestone settled in the continental shelf, weak zones are formed if the clay, instead of carbonate, is interposed between stylolits during settling process. Besides, small pores occur as a result of meltings caused by surface conditions and gaps between grains of quick settling and larger pores are resulted from being karsted.

Brown Espera: Due to insufficient degree of cementation in these limestone origin marbles and the effects of tectonic movements (strain and stress), capillary cracks in form of spiders and which develop in different directions occur in their bodies. In addition, calcite cemented holes with diameters similar to the plates and strips and generally around are formed due to penetration and melting effect of water with excessive amounts into the strain cracks.

General procedure: By cutting on gang-saw blocks larger than 5 m^3 and those between 3.5-5.0 m^3 on block cutters (ST) which are brought from marble quarries to processing plants, constant width free length strips are produced. As the result of long term experimental studies performed in plant environment, the most suitable filling-reinforcing method for the plates and strips of each marble type are determined. Then, performance measures are performed in order to properly determine how the preferred filling-reinforcing methods affect the breaking ratio.

As the result of the preliminary studies performed in plant environment, it is determined that the most efficient filling-reinforcing method for Elazig Visne plates is application of fiber mesh + epoxy on the rear surface and epoxy + epoxy gel on the front surface. Primarily, an epoxy mixture with low viscosity and a percentage of 4 units epoxy and 1 unit stiffener by weight is applied to plates heated between 25-30 °C on plate filling machine. Then, 2 mm^2 braided (65 g/m^2) mesh is laid on the epoxy and a second layer of epoxy mixture is applied on the mesh. In this process, an average epoxy mixture of 120 g/m^2 is used. The said plates are kept in ovens with elevators at 65 °C for polymerization for 2.5-3.0 h and then calibrated after leaving for curing for 3-4 days.

For the proper filling-reinforcing of the front surfaces of the plates with reinforced rear surfaces, any dust and clays in the cracks preventing epoxy penetration are cleaned and the water on the plate surface is removed with the help of fans and left for 1 day to dry. A mixture with a very high viscosity and 4 units epoxy gel and 1 unit stiffener in weight is used on the plates which are ready for front surface filling-reinforcing process after passed through preliminary heating tunnels on the filling machine. 40 g/m^2 of epoxy mixture and depending on the intensity of pores and cracks on the surface in general, an average epoxy gel mixture rate of 44 g/m^2 is applied on the front surfaces of the plates.

As the result of the experimental studies, filling-reinforcing with similar structures were not applied in polishing process and 272.03 m^2 solid plate is obtained from 523.15 m^2 Elazig Visne plate and 1072.6 m^2 solid plate from a total filled-reinforced plate of 1650.25 m^2 (Table-2).

Filling-reinforcing of Elazig Visne strips: As applied on the plates, mesh + epoxy were applied on the rear surface and after calibration epoxy + epoxy gel on the front surface of Elazig-Visne strips requiring filling-reinforcing. Because of the high level of production speed on the strip line, the filling-reinforcing appliers should keep up with such speeds. Because the blocks cut on ST have small sizes and more faults and defects, using rate of the block is lower than that of cut-rock.

110 g/m^2 epoxy mixture is used on rear surface fiber mesh + epoxy application of the strips, 34 g/m^2 epoxy mixture and 32 g/m^2 epoxy gel mixture on the front surface application. 275.84 m^2 solid strip is obtained from 429 m^2 strip on which no filling-reinforcing was applied with similar structure and which was 2 cm thick, 30 cm wide and 60 cm long and fed to the polishing line and 351.48 m^2 solid strips was obtained from 487.5 m^2 strip fed to the polishing line after filling-reinforcing (Table-3).

Filling-reinforcing of sand wave plates: Some part of sand wave marble plates and strips contain stilolite (veins), cracks, large pores and another important part contains intensive micro pores. Front surface epoxy + epoxy gel was applied on those with veins, cracks and large pores and surface filling with ultraviolet chemicals was applied on those with intensive micro pores.

As the result of the experimental studies, 1543.8 m^2 solid plate was obtained from 2165.20 m^2 sand-wave plate without applying filling-reinforcing with similar structure and which was fed to the polishing line. On the other hand, 6789.13 m^2 solid plate was obtained from 8572.13 m^2 plate fed to the polishing line by applying front surface epoxy + epoxy gel. Ultraviolet resin filling was applied to plates which does not require reinforcement with epoxy and contain intensive micro pores on the surface after calibration. Because sufficient stiffening was not achieved in pores with depths over 5 mm, benzoline peroxide stiffener with a mixture percentage of 1 % in weight was used[8]. Breaking rates of plates to which UV resin was applied and not applied were close to each other but because plates gained an aesthetical view after UV filling and kept their appearance for long period, they were sold with high prices. 3523.89 m^2 plate to which UV filling was applied and not applied was fed to the polishing line and in both situations *ca.* 3213.78 m^2 plate was obtained (Table-2).

Filling-reinforcing of sand wave strips: After the surface calibration was performed for the strips 2 cm thick, 30 cm wide and 130 cm long requiring filling-reinforcing, their crack and pore clays were cleaned. Then front surface epoxy + epoxy gel was applied on the strip filling machine. During this application, the amount of filling material corresponding to unit area was very close to the plate filling-reinforcing process.

296.38 m^2 solid strip was obtained from 406 m^2 strip without applying filling-reinforcing with similar structure and which was fed to the polishing line and 410.67 m^2 solid strip was obtained from 507 m^2 plate fed to the polishing line by applying filling-reinforcing (Table-3).

Filling-reinforcing of brown Espera plates: Because capillary crack and pore problems were present on almost all of the brown Espera plates, it is determined that it requires filling and reinforcing. The plates were calibrated after mesh + epoxy was applied on their rear surfaces. Then epoxy + epoxy gel was applied on the front surfaces of these plates. Different from the previous applications, epoxy gel with light brown-cream colour suitable to the colour of the marble was used. In addition, scraps obtained from the same marble were used in filling the holes with diameters similar to the thickness of the plate in order to reduce the consumption of chemicals. On the rear surface 139 g/ m^2 and on the front surface 46 g/m^2 epoxy mixture and 42 g/m^2 epoxy gel mixture was used.

TABLE-2
EFFECT OF SLAB FILLING-REINFORCING APPLICATIONS TO SLAB EFFICIENCY [Ref. 14]

	Non-filled-reinforced			Front surface epoxy + epoxy gel			Front surface UV			Front surface epoxy + epoxy gel, back surface fiber net + epoxy		
	A	B	C	A	B	C	A	B	C	A	B	C
Elazig cherry	523.15	272.03	48.00	–	–	–	–	–	–	1650.25	1072.6	35.00
Sand wave	2165.20	1543.79	28.70	8572.13	6789.13	20.80	3523.89	3213.78	8.80	–	–	–
Brown espera	1453.20	309.53	78.70	2147.15	693.52	67.70	–	–	–	12743.40	8767.45	31.20

A = Machine fed (m^2); B = Obtained without braking (m^2); Braking ratio (%)

TABLE-3
EFFECT OF STRIP FILLING-REINFORCING APPLICATIONS TO STRIP EFFICIENCY [Ref. 14]

	Non-filling-reinforced			Front surface epoxy + epoxy gel			Front surface epoxy + epoxy gel, back surface fiber net + epoxy		
	A	B	C	A	B	C	A	B	C
Elazig cherry	429	275.84	35.70	–	–	–	487.5	351.48	27.90
Sand wave	406	296.38	27.00	507.00	410.67	19.00	–	–	–
Brown espera	375	201.00	46.40	2342.87	1673.43	28.57	4314.4	3301.45	23.48

A = Machine fed (m^2); B = Obtained without braking (m^2); Braking ratio (%)

Only 309.53 m^2 solid plate was obtained from 1453.2 m^2 plate without filling and reinforcing and which is fed to the polishing line. On the other hand 693.52 m^2 plate was obtained from 2147.15 m^2 plate to which only front surface epoxy + epoxy gel was applied. 8,767.45 m^2 solid plate was obtained from 12,743.4 m^2 plate fed to the polishing line by applying front surface epoxy + epoxy gel and rear surface mesh + epoxy was applied (Table-2).

Filling-reinforcing of brown Espera strips: The filling-reinforcing methods used on brown Espera plates were also applied on strips. 201 m^2 solid strip was obtained from 375 m^2 strip which was 2 cm thick, 30 cm wide and 130 cm long and fed to the polishing line without filling-reinforcing, 1,673.43 m^2 from 2,342.87 m^2 strip fed to the polishing line by only applying front surface epoxy + epoxy gel and 3301.45 m^2 solid strip from 4,314.4 m^2 strip fed to the polishing line by applying front surface epoxy + epoxy gel and rear surface mesh + epoxy (Table-3).

RESULTS AND DISCUSSION

It is determined that the filling-reinforcing applications significantly improved the efficiency of plates and strips (Tables 2 and 3).

In plates: (i) Breaking percentage of Elazig-Visne plates to which front surface epoxy + epoxy gel and rear surface mesh + epoxy was applied decreased from 48 to 35 %. (ii) Breaking percentage of Sand-Wave plates to which front surface epoxy + epoxy gel was applied decreased from 28.7 to 20.8 %. (iii) Breaking percentage of Sand-Wave plates to which only surface filling was applied by using ultraviolet chemical did not vary significantly. (iv) Breaking percentage of brown-Espera plates to which front surface epoxy + epoxy gel was applied decreased from 78.7 to 67.7 % and the breaking percentage of plates to which front surface epoxy + epoxy gel and rear surface mesh + epoxy was applied decreased from 78.7 to 31.2 %.

In strips: (i) Strip breaking percentage of Elazig-Visne strips to which front surface epoxy + epoxy gel and rear surface mesh + epoxy was applied decreased from 35.7 to 27.9 %. (ii) Strip breaking percentage of Sand-Wave strips to which front surface epoxy + epoxy gel filling-reinforcing was applied decreased from 24 to 21 %. (iii) Strip breaking percentage of Brown Espera strips to which only front surface epoxy + epoxy gel filling-reinforcing was applied decreased from 46.4 to 28.57 %. (iv) Breaking percentage of Brown-Espera strips to which front surface epoxy + epoxy gel and rear surface mesh + epoxy was applied decreased from 46.4 to 23.4 %.

The cost of filling-reinforcing applications is calculated taking into consideration the consumption of energy, workmanship, investment, depreciation, maintenance-repair, mesh and chemical materials. The economic income provided taking into consideration the cost of plate-strip filling-reinforcing cost, breaking percentages and their sales prices in the market are given in Tables 4 and 5.

TABLE-4
SLAB FILLING-REINFORCING COST ANALYSIS [Ref. 14]

	Filling-reinforcing method	Slab status	Quantity of slab fed to polishing machine (m^2)	Total filling-reinforcing cost ($/$m^2$)	Quantity of slab obtained without braking (m^2)	Polished slab selling price ($)	Income ($)	Filling-reinforcing outgoing ($)	Total additional benefit ($)	Additional benefit ($/$m^2$)
Elazig	Front surface epoxy + epoxy gel, back surface fiber net + epoxy	Non-applicated	1650	0	858	95	81522	0	0	
		Applicated	1650	2.50	1072	95	101902	4127	16253	9.84
Sand wave	Front surface epoxy + epoxy gel	Non-applicated	8572	0	6112	30	183358	0	0	0
		Applicated	8572	1.17	6789	30	203673	10026	10289	1.20
	Front surface UV	Non-applicated	3523	0	3213	27	86772	0	0	0
		Applicated	3523	0.89	3213	30	96413	3158	6482	1.83
Brown espera	Front surface epoxy + epoxy gel	Non-applicated	2147	0	457	35	16007	0	0	0
		Applicated	2147	1.19	693	35	24273	2555	5711	2.66
	Front surface epoxy + epoxy gel, back surface fiber net + epoxy	Non-applicated	12743	0	2714	35	94999	0	0	0
		Applicated	12743	2.53	8767	35	306851	32239	179612	14.09

TABLE-5
STRIP FILLING-REINFORCING COST ANALYSIS [Ref. 14]

	Filling-reinforcing method	Slab status	Quantity of slab fed to polishing machine (m^2)	Total filling-reinforcing cost ($/$m^2$)	Quantity of slab obtained without braking (m^2)	Polished slab selling price ($)	Income ($)	Filling-reinforcing outgoing ($)	Total additional benefit ($)	Additional benefit ($/$m^2$)
Elazig	Front surface epoxy + epoxy gel, back surface fiber net + epoxy	Non-applicated	487	0	313.45	45	14105	0	0	0
		Applicated	487	2.51	351.48	45	15816	1224	487	1.0
Sand	Front surface epoxy + epoxy gel	Non-applicated	507	0	370.11	20	7402	0	0	0
		Applicated	507	1.18	410.67	20	8213	598	213	0.4
Brown espera	Front surface epoxy + epoxy gel	Non-applicated	2343	0	1255.78	21	26371	0	0	0
		Applicated	2343	1.20	1673.43	21	35142	5177	3593	1.5
	Front surface epoxy + epoxy gel, back surface fiber net + epoxy	Non-applicated	4314	0	2312.52	21	48563	0	0	0
		Applicated	4314	2.54	3301.45	21	69330	5951	14816	3.4

Conclusion

As the result of the mechanic resistance given to the marble through filling-reinforcement applications in each of the three marble groups, breaks which occurred during polish are largely prevented and a significant amount of economic income is gained (Tables 4 and 5).

(i) Applying front surface epoxy + epoxy gel and rear surface mesh + epoxy, 214.53 m^2 solid plate is obtained from 1650.25 m^2 Elazig Visne plate fed into polishing line with an output increase of 13 %. A total of 179612 $ additional income is gained with 9.8 $ per m^2. With Brown Espera marble on which the same method was applied, 6052 m^2 solid plate is obtained from 12743 m^2 plate fed into polishing line with an output increase of 47.5 %. A total of 179612 $ additional income is gained with 14 $ per m^2.

(ii) Applying front surface epoxy + epoxy gel, 677.2 m^2 solid plate is obtained from 1650.25 m^2 Sand Wave plate fed into polishing line with an output increase of 7.9 %. A total of 110289 $ additional income is gained with 1.2 $ per m^2. With Brown Espera marble on which the same method was applied, 236.19 m^2 solid plate is obtained from 2147.15 m^2 plate fed into polishing line with an output increase of 10 %. A total of 179612 $ additional income is gained with 2.6 $ per m^2.

(iii) Ultraviolet resin; surface filling is applied on solid plates with intensive micro porous structure with UV resin and it is observed that breaking ratio did not significantly change. But as the result of improving the product quality and adding aesthetics *via* UV application, a total of 6482 $ additional income is gained with 3 $ per m^2 from 3523.89 m^2 Sand Wave plate.

(iv) Applying front surface epoxy + epoxy gel and rear surface mesh + epoxy, 38.03 m^2 solid strip is obtained from 487.5 m^2 Elazig Visne strip fed into polishing line with an output increase of 7.8 %. A total of 487 $ additional income is gained with 1 $ per m^2. With Brown Espera marble on which the same method was applied, 988 m^2 solid strip is obtained from 4314.4 m^2 plate fed into polishing line with an output increase of 22.9 %. A total of 14816 $ additional income is gained with 3.4 $ per m^2.

(v) Applying front surface epoxy + epoxy gel, 40.5 m^2 solid strip is obtained from 1650.25 m^2 Sand Wave strip fed into polishing line with an output increase of 8 %. A total of 213 $ additional income is gained with 0.4 $ per m^2. With Brown Espera marble on which the same method was applied, 988 m^2 solid strip is obtained from 2147.15 m^2 strip fed into polishing line with an output increase of 22.9 %. A total of 14816 $ additional income is gained with 3.4 $ per m^2.

No chemicals or methods exist which may be directly applied to a marble product requiring filling and reinforcement. When choosing the application method, the intensity of the defects and faults and physical conditions of the marble such as cracks, pores, clay filling should be considered. Furthermore, filling chemical, characteristics and interactions of the marble should be taken into account. Choosing the most suitable chemical by performing detailed pre-studies together with material manufacturers increases the success rate.

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