MARBLE POWDER AS STABILIZER IN NATURAL CLAYEY SOILS

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ABSTRACT: *The physical properties of natural clayey soils are generally improved with the addition of admixtures like lime and cement. The demand of lime and cement has been increasing in the construction industry which causes increasing their cost. Efforts therefore have been carried out since long time to use the materials as admixtures which are obtained as waste from the manufacturing processes. These wastes need special arrangements for proper disposal and pose serious health and environmental hazards if are not disposed properly. Marble powder is an easily available waste product obtained during the cutting and grinding processes of the marble pieces. The marble powder has been used as a constituent in cement concrete, mortars, grouts and in resin grout as well as filler. This paper presents the details and results of an experimental study to investigate the use of the marble powder as a stabilizer to strengthen the weak natural clayey soils. The soil samples were taken at different places of Nawabshah town, Pakistan, while the marble powder was obtained from the local market. The marble power in proportions of 4, 8, 12, 16 and 20% by weight of spoil were added to the soil. Laboratory tests were carried out to determine the various properties like particle size distributions, maximum dry density, optimum moisture content, bearing capacity and swelling ratio. The test results showed remarkable improvements in the physical properties of the clayey with the addition of marble powder, which can be used in practice as a potential stabilizer to strengthen the weak natural clayey soils.*

Keywords *Clayey soil, marble powder, soil stabilizer, physical properties, baring capacity*

INTRODUCTION

The world witnesses a trend nowadays, i.e. "Utilizing the waste material for the improvement/strengthening of the poor soils". The main reason following the trend is the production of a large quantity of wastes like plastics, rice husk ash, fly ash and other industrial and agricultural wastes. These wastes cause the deposition problem and serious environmental concerns also. In order to resolve these problems one of the venues is to use these materials in different civil engineering projects [1]. A good auspicious technology regarding to utilize these wastes regarding the civil engineering projects is the soil stabilization [2]. Since decades, industrial products like lime and Portland cement are in use to attain good quality of the civil works, although these have proven to be very costly [3-6]. A major problem with the common soil stabilizing agents (i.e., OPC and Lime) is their manufacturing procedures being energy demanding and exhaling a big amount of Carbon-di- Oxide (CO_2). Almost one ton of CO_2 is transmitted during manufacture of one ton of cement [7, 8]. Marble has been used as a material for buildings since old-age. Expulsion of waste of the marble industry in very thin powder form is one of the major environmental issues today throughout world [9]. Brazil, Sweden, Italy, Spain, Belgium, Greece, Portugal, USA, France, Egypt and Turkey are among those countries owing huge marble stocks [10-13]. While cutting the marble into required length and finishing etc to use it in different applications, the marble powder and aggregate results in the byproducts, especially during the process of cutting 20-30% marble fragment converts into powder. Thus, millions of tons turn into the waste material from the treatment plants of marble. These wastes are mostly dumped-off somewhere around residential areas. It is almost impossible for these wastes to be stocked; hence, wastes of marble cause environmental pollution also [10]. Thus, it creates lots of environmental problems if not properly disposed off [11]. Today in different parts of the world the marble powder is being utilized as raw material or reinforcing material [14], such as ceramics [15], cement additives [16], de-Sulphurization processes [17], infiltration [18] and bricks [19]. Furthermore, the marble powder is also utilized in the production of white cement, mortar, mosaics, plaster, tile [20] and for the manufacturing of polymer composite material [21, 22]. Literature reports the research conducted to use marble wastes and granite for the manufacturing of clay type materials [15]. The wastes of coarse marble are reported to use as aggregates [21] while the in powder form it is used as filler in asphalt cement [23] and resin grout **[24]**. Furthermore, the Marble powder may be used for production of the polymer based composite materials [25-27]. Research discovers that the wastes of marble sludge can also be used to generate clinker [26] and also as a preservative material in mortar [28]. The other applications of marble powder waste cover its use as stone mastic asphalt application [29, 30]. This led to the idea to undertake an experimental study to investigate the suitability of marble powder as a stabilizer in the weak natural clayey soils.

PLAN OF STUDY

The present study comprises an experimental investigation and is aimed at to investigate the suitability of marble powder to be used as the stabilizer for increasing the strength of weak clayey soil of Nawabshah town (Pakistan).To achieve the aim, a series of the tests was conducted in order to determine the various properties, such as particle size distribution, consistency limits, soil classification, optimum moisture content, moisture-density relationship (maximum dry density),shear parameters, bearing capacity, and swelling ratio of the local clayey soil with different proportions of the marble powder. The results ware compared with the corresponding properties of the soil without marble powder in order to study the suitability of marble powder as stabilizer in the natural clayey soil of Nawabshah town.

MATERIALS AND METHODS

Materials

The following materials have been used in the tests.

Clayey soil

Soil used in this study was a clayey soil. The soil was obtained by making pits of about two meters deep below the ground level at different places of Nawabshah town.

Marble powder

Marble powder is basically a waste product and is produced during the cutting and grinding process of the marble pieces [10]. It is easily available from the marble cutting shops in the local market. It was in lumps which were broken to the size passing from #40 sieve. Marble powder is added in the soil from 0% to 20% with an increment of 4% by weight of dry soil.

Test samples

Six batches of samples with different clay-marble powder composition in terms of percentage by weight were considered as detailed in **Error! Reference source not found.**.

Table 1: Details of clay-marble powder composition

S.No	Specimen	Clay	Description
1	SMP_0	100	Soil without marble powder
2	SMP_4	96	Soil with 4% of marble powder
3	SMP_8	92	Soil with 8% of marble powder
4	SMP_{12}	88	Soil with 12% of marble powder
5	SMP_{16}	84	Soil with 16% of marble powder
6	SMP_{20}	80	Soil with 20% of marble powder

Laboratory tests

Error! Reference source not found.gives details of the tests conducted and properties of the soil determined from the respective tests. All the tests were performed in accordance to the standard methods.

Table 2 Details of tests and the determined properties of the soil samples

S	Name of test	Properties	Standards or method
1	Sieve	Particle size	ASTM D422
2	Consistency	Liquid limit	ASTM D4318
3	Classification	Type of soil	AASHTO M145
4	Modified	Maximum dry	ASTM D1557
5	Swelling	Swelling ratio	Prakash & Sridharan
6	Shear box	Cohesion of soil	ASTM D3080

DISCUSSIONS OF TEST RESULTS

The test results/ values were recorded and processed accordingly. The results are presented in tabular and graphical form. The comparison of the each property of soil studied is tabulated in terms 'ratio' between that of the soil without marble powder to the corresponding value of the soil with different percentage of marble powder.

Particle size distribution

Figure 1 comprises the PSD curves drawn from the results of the sieve analysis. It may be observed from the figure that the particle size distribution of clayey soil was not affected with the addition of the marble powder because the marble powder was also sieved from #40 sieve having almost same gradation as clayey soil. Thus, the addition of the marble powder is independent to affect the PSD of the clayey soils tested.

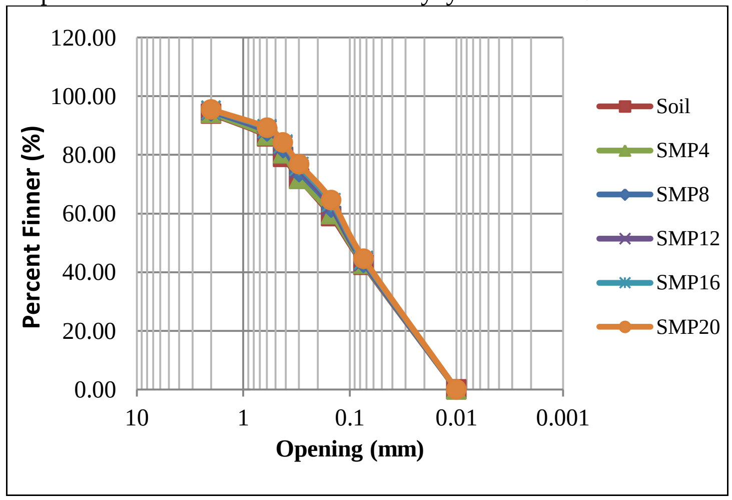

Figure 1 : Particle size distribution Curves

Consistency limits and classification of the soil

The results of the consistency limits (Plastic and Liquid Limit) determined for soils with and without marble powder are composed in Table 3. The table also contains the classification of the soil carried in accordance to AASHTO soil classification.

The table values are self evident to the fact that the addition of marble powder in the soil has shown a significant effect on the consistency limits and classification of the soil. It may be observed that the liquid limit and plastic limit reduced by 30% and 29%, respectively, when 20% marble powder is added in the clayey soil. Consequently the plasticity index is also reduced and the maximum reduction in the plasticity index recorded is 41% in case of soil with 12% of the marble powder when PI is 0.59 times of that of the clayey soil without marble powder.

This infers the significant and beneficial role of the marble powder in terms of the consistency of soil when used as a stabilizer of the soil. During the present study the soil samples were classified according to the AASHTO classification and the results are presented in Table 4. It is evident that the addition of marble powder improves its quality (general rating for sub-grade).The clay soil without marble powder is classified as A-7-5 which is rated as poor and the soil with 20% MP is found to be A-4 soil which is rated as fair. Further, it is to be noted that the MP added was passed from #40 sieve and A-4 is primarily placed in the group of fine soils. It is expected that if the marble fragments in place of marble powder are added in the soil, the soil may have been grouped in A-2. However, this aspect may be investigated further accordingly.

Moisture-Density Relationship

The results of modified proctor compaction (moisture-density relationship) are summarized in Table 4 in terms of maximum dry density and optimum moisture content. The addition of marble powder in clayey soil increased the maximum dry density of the soil and decreased the corresponding moisture content values.

Table 3 Results of particle size distribution tests

Sample Designation	SMP_0	SMP_4	SMP_8	SMP_{12}	SMP_{16}	SMP_{20}
Proportion through No.	42.48	42.82	43.20	43.49	44.05	44.57
Group	A-7-5	A-5	A-5	A-4	A-4	A-4
Plasticity	10.12	7.94	6.29	5.99	6.68	7.11
Ratio	---	0.78	0.62	0.59	0.66	0.70
Plastic limit	37.58	36.16	34.16	32.01	29.02	26.79
Ratio	---	0.96	0.91	0.85	0.77	0.71
Liquid limit	47.7	44.1	41.1	38.0	35.7	33.9
Ratio	---	0.93	0.86	0.80	0.75	0.71

The dry density was increased to 1.21 times and the corresponding moisture content was reduced to 0.64 when 20% marble powder was added in the clayey soil. This behavior of the soil may be attributed to the non-plastic behavior of the marble powder added in the highly plastic clay soil, facilitating the compaction at lower OMC and resulting in higher corresponding maximum dry density.

Figures 2 and 3 compare the results of the maximum dry density and OMC values without and with different percentages of marble powder added in the soil.

Table 4 Results of modified proctor's tests

Sample Designation	SMP_0	SMP_4	SMP_8	SMP_{12}	SMP_{16}	SMP_{20}
$\gamma_{d(\max)}$ (gm/cm^3)	1.87	1.93	1.95	1.99	2.08	2.26
Ratio	---	1.03	1.04	1.06	1.11	1.21
OMC (%)	14.8	14.6	13.6	12.9	11.2	9.4
Ratio	---	0.99	0.92	0.87	0.76	0.64

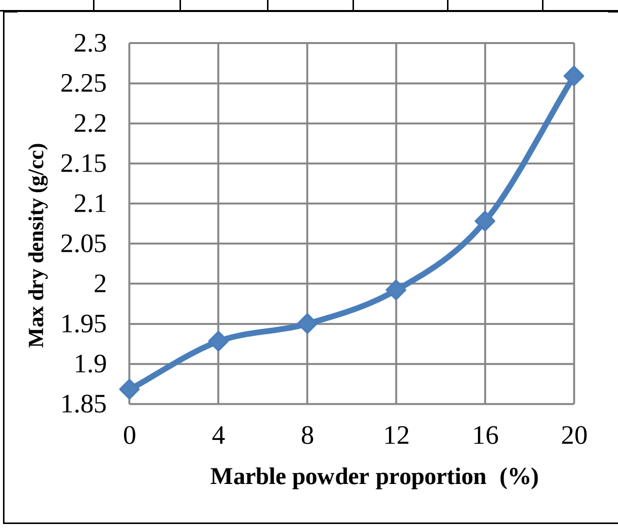

Figure 2: Maximum dry density of soli with marble powder

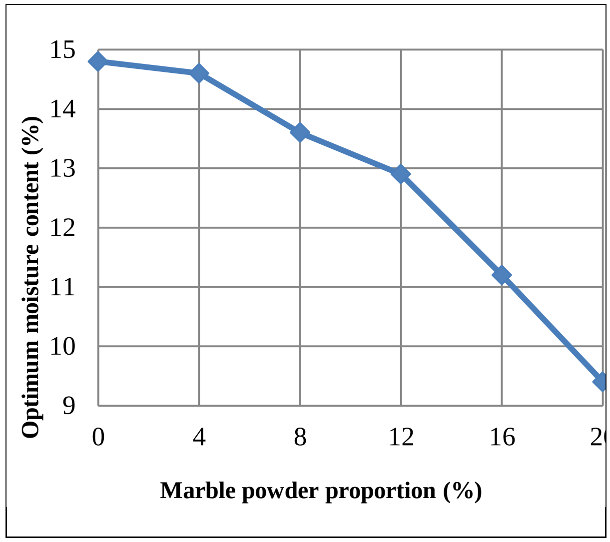

Figure 3 : OMC of soil with marble powder

Free Swell Ratio

This test was carried out to characterize the soil expansion. The test was conducted following the procedure given by Prakash and Sridharan [31]. Also, they proposed the following equation to to calculate free swelling ratio (FSR) and on the basis of FRS suggested the classification of soils in terms of the extent of expansion (swelling) as given in Table 6.

$$FSR = \frac{V_d}{V_k}$$

Where: FSR Free Swelling Ratio

V_d sediment volume of soil in distilled water

V_k sediment volume of soil in kerosene oil

The results of swelling test in terms of free swell ratio (FSR) determined are also presented in table 6 and are also classified in terms of FSR. The addition of marble powder in the soil has exhibited pronounced effect on the swelling properties of the soil. The FSR of clay reduces to 0.59 (i.e. 41% less) with the addition of 20% marble powder and the type of the soil converts from "swelling" to "non swelling" status. Also the clay sample without marble is classified as "Moderate" in terms of expansivity but its class become "Negligible" in terms of expansivity when it contains 20% marble powder. Since FSR is a measure of the capability of a soil to expand in the presence of water and vice versa (i.e. it shrinks when dried). Thus**,** the importance of FSR cannot be neglected while commencing any hydraulic project**.** Higher the FSR, more is the risk of expansion and shrinking of the soil and the addition of marble powder as a stabilizer in such soils may off-set or reduce this risk.

Shear parameters and bearing capacity

Shear box test was carried for all the soil samples and shear parameters 'cohesion apparent' (C) and angle of internal friction (Ø) were determined from the graphs accordingly. Further the shear parameters were used to determine the bearing capacity of the clay soil without and with marble powder in accordance to Terzaghi's expression [32].

Table 5 Classification of soils based on FSR [32]

Free swelling ratio	Soil expansivity	Clay type	Dominant clay mineral type
<1.0	Negligible	Non-swelling	Kaolinitic
1.0- 1.5	Low	Swelling and non-swelling	Kaolinitic and Montmorillonitic
1.5 - 2.0	Moderate	Swelling	Montmorillonitic
2.0 - 4.0	High	Swelling	Montmorillonitic
> 4.0	Very high	Swelling	Montmorillonitic

Table 6 Results of swelling tests

Specimen Designation	FSR	Ratio	Clay Type	Soil Expansivity
SMP_0	1.52	---	Swelling	Moderate
SMP_4	1.13	0.74	Mixture of Swelling and Non Swelling	Low
SMP_8	1.11	0.73	Mixture of Swelling and Non Swelling	Low
SMP_{12}	1.05	0.69	Mixture of Swelling and Non Swelling	Low
SMP_{16}	1.00	0.66	Mixture of Swelling and Non Swelling	Low
SMP_{20}	0.89	0.59	Non Swelling	Negligible

Table 7 summarizes the values of shear parameters and the bearing capacity determined. The angle of internal friction being 16^0 of the clayey soil without marble powder enhanced to25.3^0 with 20% marble powder added in it. However, 'C' reduced by 50% with the same proportion of marble powder. This indicates the convergence of the clayey soil from its status of cohesive soil to the more frictional soil which is a positive sign while classifying the soil qualitatively.

Figures 4 and5 compare the results of C and Ø of the clayey soil due to addition of different proportion of marble powder. Bearing capacity of the clayey soil increases with the increase in the marble powder proportion added in the clayey soil which is illustrated in figure 6. The clay soil with 20% marble powder exhibited 2.47 times more bearing capacity that of the clay soil without marble powder. Since bearing capacity is one of the major parameters considered during the design of foundations for the engineering projects particularly building structures; thus, it may be concluded the marble powder can be considered a potential material as stabilizer in the week soils like clay when bearing capacity is the major parameter.

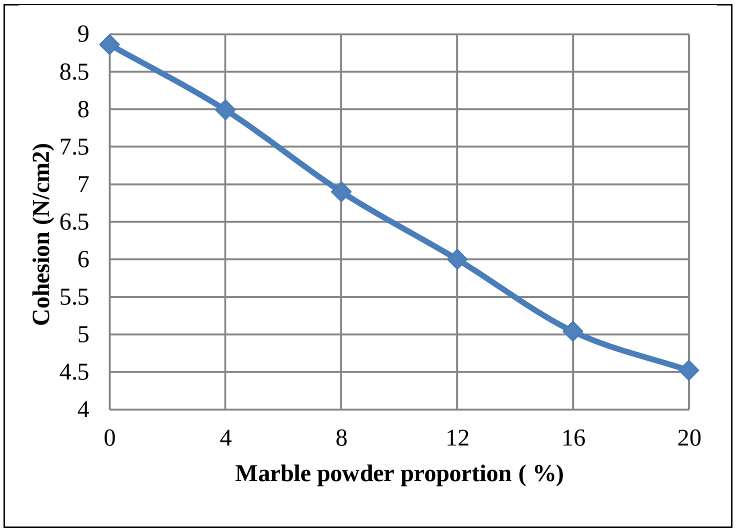

Figure 1:Cohesion apparent of soil with marble powder

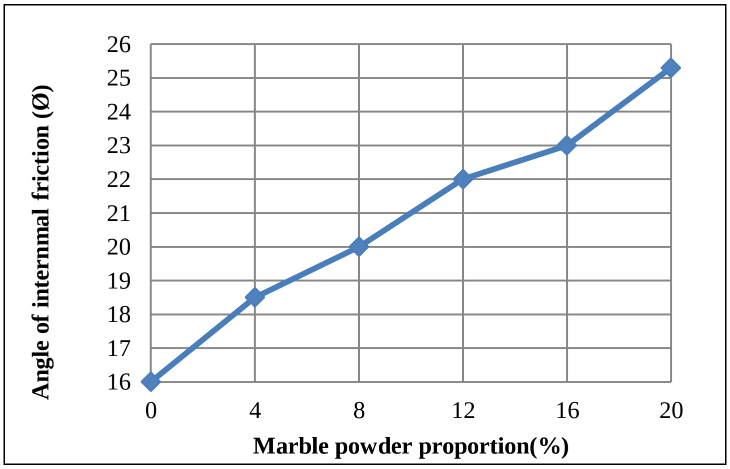

Figure 2:Frictional angel of soil with marble powder

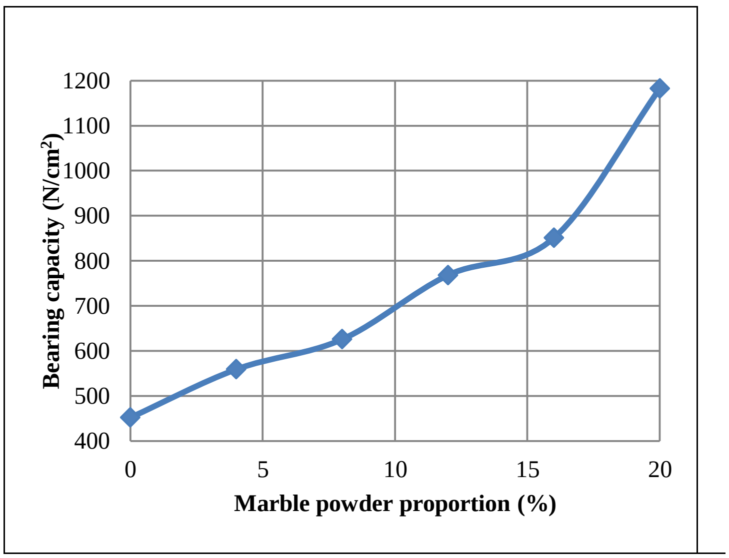

Figure 3:Bearing capacity of soil with marble powder

Table 7 Results of shear box tests

Sample Designation	C (N/cm^2)	Ratio	Ø	Ratio	Bearing capacity (N/cm^2)	Ratio
SMP_0	8.86	---	16^0	---	451.87	---
SMP_4	7.99	0.90	18.5^0	1.16	558.90	1.24
SMP_8	6.90	0.78	20^0	1.25	625.56	1.38
SMP_{12}	6.00	0.68	22^0	1.38	768.10	1.70
SMP_{16}	5.04	0.59	23^0	1.44	850.76	1.88
SMP_{20}	4.52	0.51	25.2^0	1.58	1182.20	2.47

CONCLUSIONS

The suitability of marble powder as stabilizer to improve physical properties and strength of weak natural clayey soil has been investigated with the help of a series of the laboratory tests. The soil samples were taken from Nawabshah town, Pakistan and were tested to determine the properties such as particle size distribution, optimum moisture content, dry density, shear parameters, swelling ratio and bearing capacity. The properties of clay samples were determined without and with the addition of 4, 8, 12, 16 and 20% marble powder by total weight of the samples. The results obtained from the tests are summarized as follows.

Particle size distribution of the soils remained unchanged due to the addition of marble powder because of almost similar gradation of the clayey soil and marble powder used during this study.

The liquid limit and plastic limit decrease with the addition of marble powder, thereby decreasing the plasticity index also.

The quality of soil in terms of AASHTO classification is significantly improved with the addition of marble powder. The natural clayey soil originally lying in A-7-5 group shifted to A-7-4 group, thereby converging from poor to fair category.

The addition of marble powder resulted in a remarkable increase in the maximum dry density up to 1.21 times and a decrease in optimum moisture content to 0.64 times to those of the natural clayey soil respectively.

The soil expansivity, which was 'moderate' for the clayey soil, was also improved to 'negligible' with 20% proportion of the marble powder when clayey soil was tested for free swelling ratio. The FSR of the sample with 80% clayey soil and 20% marble powder was 0.59 times that of the 100% clayey soil.

The angle of internal friction which was 16^0 for clayey soil was improved to $25.3^0$and cohesion apparent of the soil reduced by 50% with 20% proportion of the marble powder. Thus, the nature of the original soil being cohesive tends to be emerging as more frictional soil due to marble powder.

The bearing capacity of the clayey soil significantly enhanced due to the addition of the marble powder and was increased up to 2.47 times for the samples with 20% proportion of the marble powder.

The results of the experimental study conducted and discussions made herein inferred that the addition of marble powder to weak natural clayey soil has shown remarkable improvement in the physical properties and bearing capacity of the soil. It may be concluded that the marble powder may be considered a potential stabilizing component to strengthen the weak clayey soils.

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REFERENCES

[1] *JyotiS.Trivedi, Sandeep Nair, ChakradharIyyunni.* "Optimum Utilization of Fly Ash for Stabilization of Sub- Grade Soil Using Genetic Algorithm" Procedia Engineering 51: 250 – 258(2013).

[2] *DimitrisDermatas, XiaoguangMeng*. "Utilization of fly ash for stabilizing consoliding metal contaminatedsoils" Engineering Geology 70(3-4): 377–394(2003).

[3] *Sherwood PT*. "Soil stabilization with cement and lime"stateof the artreview.HNSO Publication; 1993.

[4] *Petry TM, Little DN*. "Review of stabilization of clays and expansive soils in pavements and lightly loaded structures "history, practice, and future. Journal of Materials in Civil Engineering 14(6):447–60(2002).

[5] *Consoli NC, Foppa D, Festugato L, Heineck KS*."Key parameters for strength control of artificially cemented soils." Journal of Geotechnical and Geoenvironmental Engineering 133(2):197–205(2007).

[6] *Horpibulsuk S, Rachan R, Chinkulkijniwat A, Raksachon Y, Suddeepong A*. "Analysis of strength development in cement-stabilized silty clay from micro structural considerations."Construction and Building Materials 24(10): 2011–21(2010).

[7] *Mo Zhang, Hong Guo, Tahar El-Korchi, Guoping Zhang, MingjiangTaoexperimental*. "Feasibility study of geopolymer as next generation soil stabilizer" Construction and Building Materials 47: 1468–1478(2013).

[8] *Khedari J, Watsanasathaporn P, Hirunlabh J*. "Development of fibre-based soil–cement block with low thermal conductivity" Cement Concrete Composites 27(1):111–6(2005).

[9] *Valeria Corinaldesi.GiacomoMoriconi, Tarun R. Naik*. "Characterization of marble powder for its use in mortar and concrete" Construction and Building Materials 24: 113–117(2010).

[10] *Osman Gencela, CengizOzelb, FuatKoksalc, ErtugrulErdogmusd,GonzaloMartínez-Barrerae, WitoldBrostow*. "Properties of concrete paving blocks made with waste marble" Journal of Cleaner Production 21: 62-70(2012).

[11] *HuseyinYılmazAruntas, Metin Guru, Mustafa Dayı, IlkerTekin.* "Utilization of waste marble dust as an additive in cement production" Materials and Design 31: 4039–4042(2010).

[12] *Arunta s HY, Tokyay M. U* "Stability of diatomite as a pozzolan in blended cement production. Cement Concrete World 1: 33–41 (1996) [in Turkish].

[13] *Guru M, Akyuz Y, Akın E*. "Effects of filler ratio on mechanical properties at natural stone powder/polyester composites" Journal of Polytechnique (8):271–4. (2005) [in Turkish].

[14] *N. Bilgin, H.A. Yeprem, S. Arslan , A. Bilgin, E. Gunay, M. Mars_oglu* "Use of waste marble powder in Brick industry" Construction and Building Materials 29: 449–457(2012).

[15] *Acchar W, Vieira FA, Hotza D*. "Effect of natural stone and granite sludge in clay materials" Materials Science Engineering A(419):306-309(2006).

[16] *Aruntas H, Guru M, Dayı M, Tekin I*. "Utilization of waste natural stone dust as an additive in cement production" Materials and Design 31: 4039–42(2010).

[17] *De Bresser JHP, Urai JL, Olgaard DL*. "Effect of water on the strength and microstructure ofCarrara natural stone axially compressed at high temperature" Journal of Structueral Geology 27:265–81(2005).

[18] *Davini P*. "Investigation into the desulphurization properties of by-products of the manufacture of white marbles of Northern Tuscany" Fuel 79:1363–9(2000).

[19] *Saboya F, Xavier GC, Alexandre J*. "The use of the powder marble by-product to enhance the properties of brick ceramic" Construction and Building Materials 21: 1950–60(2007).

[20] *Zorluer I Usta M*. "Stabilization of soil by waste marble dust in Proceeding of the fourth national marble symposium, Turkey, December 18–19" p.305–11(2003) (In Turkish).

[21] *Guru M, Akyuz Y, Akın E*. "Effects of filler ratio on mechanical properties at natural stone powder/polyester composites" Journal of Polytechnique 8:271–4(2005) [in Turkish].

[22] *Guru M, Tekeli S, Akın E*. "Manufacturing of polymer matrix composite material using natural stone dust and fly ash" Key Engineering Materials (336–338):1353–6.(2007).

[23] *Kara sahin M, Terzi S*. "Evaluation of marble waste dust in the mixture of asphaltic concrete" Construction and Building Materials 21: 616–20(2007).

[24] *Noor Ahmed M., Nasim U.K, Bhutto M.A., Salihuddin R.S*. "Experimental Study of Compressive strength of Resin Grout with Marble Powder", European International Journal of Science Technology (EIJST), 3(4): 87-95(2014).

[25] *Saboya F, Xavier GC, Alexandre J*. "The use of the powder marble by-product to enhance the properties of brick ceramic". Construction and Building Materials 21: 1950–60(2007).

[26] *Pereira FR, Ball RJ, Rocha J, Labrincha JA, Allen GC*. "New waste based clinkers belite and lime formulations" Cement Concrete Research 38: 511-21(2008).

[27] *Saboya F, Xavier GC, Alexandre J*. "The use ofthepowdernatural stone byproduct to enhance the properties of brick ceramic" Construction and Building Materials 21:1950–60(2007).

[28] *Arslan EI, Aslan S, Ipek U, Altun S, Yazıcıoglu S. Physico*. "Chemical treatment of natural stone processing wastewater and the recycling of its sludge" Waste Management and Research 23: 550–9(2005).

[29] *Karakus A*. "Investigating on possible use of Diyarbakir basalt waste in Stone Mastic Asphalt" Construction and Building Materials 25:3502–7(2011).

[30] *Aruntas H, Guru M, Dayı M, Tekin I*. "Utilization of waste natural stone dust as an additive in cement production" Materials and Design 31:4039–42(2010).

[31] *Prakash, K. and Sridharan, A*. "Free Swell Ratio and Clay Mineralogy of Fine-Grained Soils", Geotechnical Testing Journal, 27(2):1-6(2004).

[32] *Donald P Coduto* "Geotechnical Engineering – Principles and Practices" Prentice Hall of India Pvt Limited New Delhi India(2002).