Effect of Plastering on Clay Brick Masonry Behavior using Taguchi Method

Nasser, A.A

Department of Civil Engineering. Faculty of Engineering, Minoufiya University. Shebin-Elkom, El-Minoufiya, Egypt,

Abstract

Clay brick is used as infill buildings partitions. Plastering these infill walls may be postponed or eliminated. The effect and optimization of using interface overlays on masonry behavior was investigated by using Taguchi method as a new technique in experimental design. The experimental studies were conducted using different types of brick in order to study the masonry behavior. Two control factors were taken into consideration; number of mortar interface overlays (A) and clay brick type (B). Nine walls were constructed and tested under compressive loading. Longitudinal Strain of each wall was recorded under loading. The data was analyzed, two mortar overlays and brick type 1 wall has the best performance. Analysis of Variance of experimented walls showed high contribution of plastering compared with brick type. It was concluded that plastering the walls from both sides enhanced the behavior of the walls. One mortar overlay decreases the compressive loading of wall.

Keywords: Clay Brick, Masonry, Tagushi Method, Compressive strength, Plastering, Mortar Interface.

1. Introduction

When clay bricks are heated to high temperature, series of chemical reactions occur. High temperature creates crystalline phases in clay. Brick becomes permanently hard and durable (H. C. Lima Júnior et al, 2003). Chemical modification of clay material during firing improves mechanical strength. Physical and chemical properties of brick are related to clay minerals composition. Same clay yield different results when fired at different temperatures (S. Karaman et al, 2006). Microstructure and mineral fillings depend on brick calcareous composition and firing temperature (G. Cultrone et al, 2005). Brick durability is mainly influenced by pore structure and material strength (P. Lopez-Arce et al, 2005).

Salts may be inherent to brick, mortar, absorbed groundwater, created by metabolic activity of microorganisms, or formed by reaction with atmospheric pollutants. Efflorescence is a fine, white, powdery deposit of water-soluble salts left on the surface of masonry as water evaporates. Alkali sulfates in walls are dissolved by water into a solution which moves through natural pores in masonry. The solution migrates to wall surface, where water evaporates. Depositing salts rest on walls. Deposits are white powdery known as efflorescence. Potential efflorescent problems can be greatly reduced by using low alkali cements, clean washed sands and potable free salt water (R. Boynton et al, 1990)

Masonry construction is a very old building technique. Potential damage of unreinforced masonry facing lateral loads is a human life threat particularly in the out-of-plane direction (X. Wei et al, 2010). Masonry is used as infill walls in reinforced concrete buildings (H.B. Kaushik et al, 2007). Masonry walls are used in all types of building construction all over the world. Clay-unit masonry is composed of two materials; mortar and fired-clay brick (W.S. Mcnary et al, 1985). Masonry is provided and expected to resist compressive forces only. Structural engineers often ignore infill walls presence. Walls tend to interact with the surrounding frame, when the structure is subjected to lateral forces; the resulting system is referred to as infilled frame. Brick masonry wall imparts additional flexural strength due to beneficial interaction with its supporting reinforced concrete beam. Structural interaction results in a considerable increase in the stiffness of the overall structure. In conventional methods of design of concrete structures, the brick masonry is dead load on supporting beams. Modern structural analysis considers the entire structure as a single unit. The wall-beam composite is an example for the composite behavior of brick masonry and reinforced concrete structures (H.B. Kaushik et al, 2007).

2. Design of Experiment Based on Taguchi's Technique

Statistical design of experiments refers to experimental planning process, so that data is analyzed by statistical

method, resulting in valid and objective conclusions. Design of experimental methods such as factorial design, response surface methodology (RSM) and Taguchi methods are now widely used in place of one-factor-at-a time in experimental approach (R. K. Roy, 2001).

The major steps required for the experimental design using Taguchi method are: (1) establishment of objective function, (2) identification of factors and their levels, (3) selection of an appropriate orthogonal array (OA), (4) experimentation, (5) analysis of data and determination of the near optimum level of each factor (optimum combination), and (6) the confirmation experimentation (R. K. Roy, 2001).

3. Work Objective

Reinforced concrete skeleton construction is the most popular in Egypt. Clay brick is widely used in the construction system as partitions. Plastering these infill walls may be postponed or eliminated, particularly the outer walls adjacent to other buildings. The effect and optimization of using interface overlays on masonry behavior was investigated in this study by using Taguchi method. It is a new technique in experimental design. The experimental studies were conducted using different number of overlays and types of brick to study the masonry behavior. Two control factors were taken into consideration; number of interface overlays (A), and clay brick type (B).

4. Taguchi's Orthogonal Array Approach of Experimental Design

Taguchi proposes a holistic view of quality which relates quality to cost. Taguchi defines quality as, "The quality of a product is the (minimum) loss imparted by the product to the society from the time product is shipped". When a critical quality characteristic deviates from the target value, it causes a loss. Quality simply means no variability or very little variation from target performance. Variability reduction or quality improvement drives cost down. Lowest cost can only be achieved at zero variability from target. Variability reduction from the target value is critical quality characteristics. High quality and cost reduction are achieved. Design engineers actually calculate the optimum design based on cost analysis and experimentation. Taguchi's target is developing products that achieve target value on consistent basis. Quality is achieved by minimizing the deviation from the target. A number of parameters can influence the quality characteristic or response of the product. The scope is limited to optimize compressive strength for masonry (R. Unal et al, 1991).

The method of investigating all possible combinations and conditions in an experiment (involving multiple factors) is traditionally known as factorial design. The number of possible design N (number of trials) is $N=L^m$, where L=number of levels for each factor, m=number of factors involved. Qualities for masonary depend on two factors. Variation of three levels conditions is limited to the number of design of experiments of $3^2 =9$ trials.

4.1. Selection of Orthogonal Array (OA)

Minitab software version 16 is used to develop the experimental plan for Taguchi method. The same software is also used to analyze the measured data. Moreover, the analysis of variance (ANOVA) was used to discuss the relative importance of control factors and its contribution.

Taguchi (R. Unal et al, 1991) designed certain standard orthogonal arrays (OA). There are many standard orthogonal arrays available. Each array is meant for a specific number of independent design variables and levels. Behavior of two control factors each of three levels is investigated. Use of a full factorial design gives a total of 9 (2^3) sets of experiments. Therefore, L9 OA is selected for the present investigation. The two independent variables (control factors) and their three levels are presented in Table (1).

Table 1 Orthogonal Array of Taguchi Design L9 & Control Factors

Masonry	L9 Design		Experimental Factors	
	Factor A	Factor B	No. of Interface layers	Type of brick
W1	1	1	No plastering	B1
W2	1	2	No plastering	B2
W3	1	3	No plastering	B3
W4	2	1	One layer interface	B1
W5	2	2	One layer interface	B2
W6	2	3	One layer interface	B3
W7	3	1	Two layer interface	B1
W8	3	2	Two layer interface	B2
W9	3	3	Two layer interface	B3

5. Experimental Work

5.1. Materials

The constituent materials used in this study were locally available materials specified by the following:
1. Brick units: clay brick units (10 vertical holes) were obtained from three different factories in El-Menoufia Province, Egypt.
2. Cement: Ordinary Portland cement with grade 32.5N was used in this investigation. Cements are confirmed to the Egyptian Standard Specifications (ES) requirements (2421-1/2005).
3. Fine aggregates: Medium well-graded sand of fineness modulus 2.2 was used for mortar. Fine aggregates confirming to ES requirements (1109-2002).

5.2. Specimen Preparation and Testing

Clay brick specimens were tested according to ECP (204-2005). The mortar mixture was weighed and mixed manually in a batch of 250 L for a period of 10 min. Clay brick units were kept in water prior to construction as specified in (ECP 204-2005). Mortars proportions were in accordance to (ECP 204-2005) and testing manual. Ratio by volume was 1:3 for cement: sand, respectively, and the water-cement ratio of 1.3 (with water added until desired workability is achieved. Mortar cubes (70x70x70 mm) were cast during construction of test specimens. Mortar compressive strength was 180MPa after28 days. Masonry prisms were made to measure compressive strength after 28 days. They were cured in the laboratory condition. All strengths of masonry prisms were calculated by using the gross area under loading (ESS 1756/1989). Hydraulic testing machine of 1550 kN total capacity was used for testing masonry prisms as shown in figure (1.a). Failure of prism under compressive loading is shown in figure (1.b). Nine wall specimens were constructed by using three different brick units and one type of mortar to achieve straight wall height of 750 mm and length of 750mm and with thickness equal to the width of brick unit. Mortar used for bed and head joints has a thickness of about 20 mm. After seven days from construction, the walls were covered with 20 mm overlays thickness for each layer. Steel plate 50mm thick corresponding to concrete beam was put on the top of walls to distribute uniform load. A hydraulic load cell with 500 kN total capacity was used to test walls after 28 days. Applied loads and mid height longitudinal strain (with 200 mm gauge length) were recorded for each specimen.

a. testing masonry prisms   b. Failure of Prism

Figure 1 Prism under Compressive Loading Using

6. Test Results

The mechanical properties of brick units are given in Table (2) (in accordance to ES: 1524/1993) and ECP-testing manual. The area of holes is less than 25% of total surface area of brick units. Thus the loading area equal to the gross area. Table (2) illustrates the experimental test results of brick units.

Table 2 Physical Properties of Clay Brick

Brick	Dimension (mm)			Absorption %[*]	Voids	Efflorescence[**]
	Length	Breadth	Height			
Specification Limit	250±2	120±2	70±2	<16%	--	<50%
B1	229	106	72	11.92	20.3	10
B2	231	108	71	8.07	20	50
B3	229	104	71	9.95	21	60

* for bearing walls, ** Efflorescence as percentage of white color area covering brick surface

Figure (2) shows comparison between compressive strength of brick unit, prism and walls. Walls have no plastering, one face overlay or two faces overlays. Figure (3) shows applied loads with corresponding longitudinal strain of masonry.
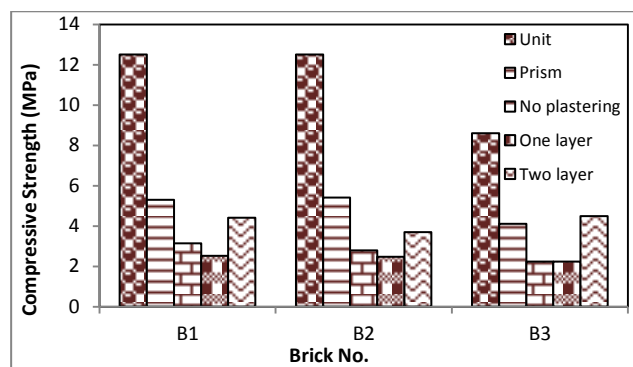

Figure 2 Compressive Strength of Brick Unit, Prism and Masonry Walls
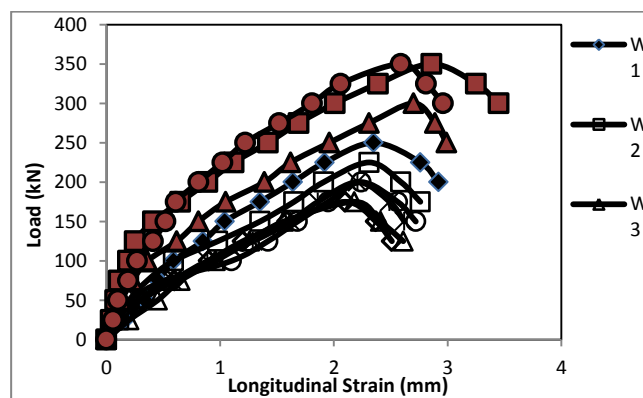

Figure 3   Load versus Longitudinal Strain of Masonry Walls

Figure (4) shows crack pattern of W4 with one layer interface. Debonding of mortar interface area is clear. Figure (5) shows crack pattern of W7. Ultimate load is 350kN for W7. Walls W7, W8 and W9 are two layer interface of mortar. Figure (6, 7) shows crack pattern of W8 and W9.

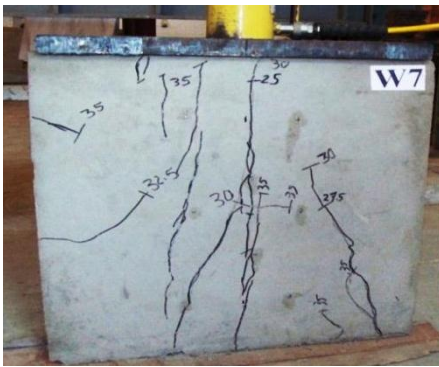**Figure 4** Crack Pattern of W4 with One Layer Interface

Figure 5 Crack Pattern of W7 with Corresponding Steel Beam
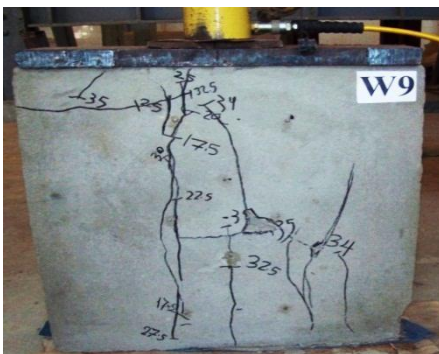

Figure 6 Crack Pattern of W8

Figure 7 Crack Pattern of W9

7. Analysis of data

Taguchi method uses a statistical measure of performance called signal to noise (S/N) ratio. The S/N ratio developed by Taguchi is a performance measure to choose control levels that best cope with noise. The S/N ratio takes both the mean and the variability into account. In its simplest form, the S/N ratio is the ratio of the mean (signal) to the standard deviation (noise). The S/N equation depends on the criterion for the quality characteristic to be optimized (U. Eşme, 2009). A loss function is defined to calculate the deviations between the experimental value and the desired value. This function is further transferred into a signal-to-noise (S/N) ratio. There are three S/N ratios available, depending on the type of characteristic; the lower-the better (LB), the higher-the better (HB), and the nominal the better (NB). In the present investigation, the objective is to maximize the strength and ductility, therefore ''larger is better'' quality characteristics are selected, which is logarithmic function can be calculated as follows (S. M. Holt, 2011):

$$\eta = \left(\frac{S}{N}\right)_i = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{Y_i^2}\right] \qquad \text{eq. (1)}$$

where the quality score y_i with larger-the-better has been assumed. The overall mean value of η over nine experiments becomes

$$\bar{\eta} = \frac{1}{9}\sum_{i=1}^{9}\eta_i \qquad \text{eq. (2)}$$

The effect of a control factor level is defined as the deviation of its related S/N ratio η from the mean value.

For example, when the effect of level A1 is concerned, we note that the control factor A is at level 1 in experiments 1-3. Hence, the average *ηA1* and effect of A are given, respectively, as

$$\eta_{A1} = \frac{1}{3}[\eta_1 + \eta_2 + \eta_3] \quad \text{Effect of } A \triangleq |max\eta_A - min\eta_A| \qquad \text{eq. (3)}$$

The response table for S/N ratio and means is given in table (3). S/N ratios at each level of control factor changed from level 1 to level 3. The control factor with the strongest influence was determined. Table (3) shows strongest influence exerted by factor A (rank 1). Factor B has (rank 2). Factor A (plastering) has bigger effect on ultimate load and compressive strength of masonry than that of factor B.
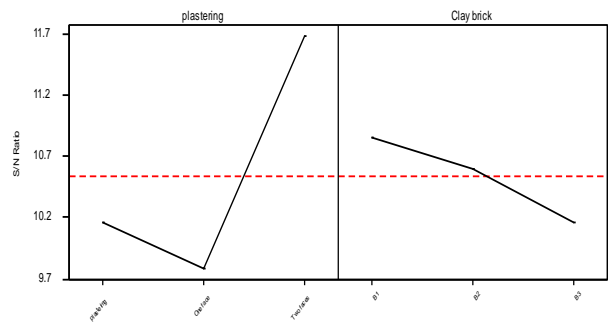

Figure 8 Main Effect Plot for Signal to Noise ratios of Masonry Compressive Strength

Table 3 Response Table for Signal to Noise Ratios and Means (Larger is better)

Level	Response Signal to Noise Ratios		Response for Means	
	plastering	Clay brick	plastering	Clay brick
1	10.164	10.861	109.47	134.575
2	9.7888	10.606	96.925	122.037
3	11.684	10.17	168.03	117.812
Delta	1.8947	0.6915	71.1	16.763
Rank	1	2	1	2

7.1. Analysis of Variance

The analysis of variance (ANOVA) (S. Rama Rao et al, 2012) is used to discuss the relative importance of control factors on quality and to determine control factors highest effect. Parameters used in ANOVA are calculated by the following equations:

$$S_m = \frac{1}{9}\left(\sum_{i=1}^{9}\eta_i\right)^2, \qquad S_A = \frac{1}{3}\sum_{i=1}^{3}\eta_{A_i}^2 - S_m, \qquad S_T = \sum_{i=1}^{9}\eta_i^2 - S_m$$

$$S_e = S_T - \sum S_{control-factor}, \qquad V_A = \frac{S_A}{f_A}, \qquad \sigma_A = \frac{S_A}{S_T}\times 100\%$$

Where Sm is the average of squares of sums, SA is the sum of squares related to control factor A, ST is the sum of squares of the errors correlated to all control factors, VA is the variance related to factor A and *fA* is the degree of freedom for factor A, FA is the F-ratio related to control factor A and σA is the percentage contribution related to control factor A. σB is calculated by similar way. The computer values for σA and σB gives relative importance of the control factors on compressive strength (B. Berginc et al, 2006).

The analysis of variance (ANOVA) is used to investigate effect of design parameters on quality characteristic. It is accomplished by separating variability of S/N ratios measured by sum of squared deviations from the total mean S/N ratio. Contributions of design parameters are calculated values of variance ratio (F). Variance of factor is divided by the error variance for all control factors (M. Ghazy, 2012).

Table 4 Analysis of Variance of Ultimate Load Using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Plastering	2	34306	34306	17152.8	21.5	0.01	87.28
Brick	2	1805.6	1805.6	902.8	1.13	0.41	4.59
Error	4	3194.4	3194.4	798.6			8.13
Total	8	39306					

ANOVA of ultimate loads is shown in table (4). Factor A (plastering) had a significant influence of walls behavior. The contribution percentage is 87.28% for compressive strength. Factor B (brick type) shows 4.59% contribution value. Number of mortar overlies factor showed the best efficiency of strengths (factor A). Figure (3) shows the recorded load - longitudinal strain curves for different walls. These curves show longitudinal strain values for all tested walls. Experiment No.7 (two faces of overlays and B1) has the best performance. That increase means higher ductility.

8. Discussion

Length and breadth dimensions of brick units are not in accordance with Egyptian Specifications. Absorption ratio lay within specification limits. High efflorescence is a result of clay compounds of salt deposits. The factories use clay from different sources of Egypt. Brick achieves ECP compressive strength of bearing walls. There is no relation between absorption and compressive strength of brick units.

Prism strength depends on masonry unit strength under biaxial tensile-compressive stresses. Failure mode of the prism is shown in figure (1). Compressive strength of prisms is proportional to brick strength. Also, behavior of masonry took the same trend. Each group of masonry is compatible with its brick unit and prism compressive strength as shown in figure (2). Mechanics of clay-unit masonry in concentric compression incorporated nonlinear behavior of confined mortar and splitting strength of a masonry unit. Although failure of a prism occurred as a result of lateral tensile splitting of a masonry unit, mortar induced tensile stresses. These stresses increased disproportionately with compressive forces because of the nonlinear deformational properties of the mortar. One layer of mortar interface wall supported compressive loading less than no plastering walls as shown in figure (2). Two faces plastered masonry could attain a higher load capacity. Two overlies mitigate and confine the effects of damages in the bricks. Thus, sudden loss of rigidity in walls without overlays was avoided.

Clay masonry is composed of mortar and clay brick materials have quite different properties. When subjected to a uniaxial compressive force, mortar has a tendency to expand laterally more than that of brick. Mortar and brick are bonded together mechanically, so the mortar is confined laterally by the brick. Shear stresses at the brick-mortar interface result in an internal state of stress. Stresses are triaxial compression in the mortar and bilateral tension coupled with axial compression in the brick. Stress state initiates vertical splitting cracks that lead to failure. This is typical for one face overlay W4 as shown in figure (4).

Signal to Noise plots reveal that plastering has a larger effect on the quality characteristic than brick type. The masonry walls without overlays showed vertical and horizontal cracks appeared at the mid part of the wall, then crack propagation was diagonally to the bottom corners. The initial crack loads were about 50% of ultimate loads. While, in the walls with two overlays, there was no debonding of the overlays from the brick as

shown in figures (5-7). The initial crack loads were about 60% of ultimate loads.

Figure (8) shows main effect for S/N ratio. This plot shows clay brick with its slope has small effect. Slope of plastering has obvious effect on S/N ratio. Optimal longitudinal strain of the control factors recorded at levels (A3B1), as shown in figure (8), this means using brick B1 and two faces of overlays. Table (4) reveal that factor A (number of mortar overlies) reached 87.2%, made the major contribution to overall performance, this is due to the impact of the mortar overlies confinement for weak bond between brick and mortar intervals. The contribution percentage for factor B (brick type) is 4.59%. Error was 8.13%.

9. Confirmation Test

The confirmation experiment is the final step in any design of experiment process. Once the optimum (most desirable) level of the design parameters was selected, the next step was to predict and verify the improvement of quality characteristic using the optimal level of the design parameters. These confirmation tests establish the new performance at the new (optimum) condition and estimate results. The result expected is considered to be confirmed when the mean of a number of samples tested at the optimum condition falls close to it. Since the nine experiments covered all possible combinations. Confirmation test is the highest levels of the control factors, which is presented in W7 (A_3B_1). Since confirmation test is already experimented among the nine walls. It is shown in figure (3), that W7 as the best behavior among all walls.

10. Conclusions

Taguchi's method of experimental design was used in this study to provide a simple, efficient, and systematic approach for the optimization of experimental designs. According to the experimental study in this work, concluding remarks are given below:
1. Application of Taguchi method for the design of experiments is easy and efficient.
2. The experimental result confirms the optimization of the process parameters using Taguchi method for enhancing the process performance.
3. The number of overlays was the most influential factor on the masonry compressive strength.
4. Application of mortar overlays increased the wall strength using two layers interface, while using one overlay was less or equal to no plastering effect.
5. Based on signal-to-noise results, the best performance in compressive strength of walls was exerted by factor A3

(number of overlay mortar) and B1 (Brick type 1). This means, brick No.1 and two faces mortar overlies.W7 presents A_3B_1.
7. Based on results of the analysis of variance ANOVA, plastering showed higher efficiency of wall strength. Contribution percentage was 87.28% for plastering and 4.59% for brick type.
8. Plastering must be applied from both sides. Using one layer decreases the compressive strength of the wall.

References

[1]. H. C. Lima Júnior, F. L. Willrich, and N.P. Barbosa, (2003), Structural Behavior of Load Bearing Brick Walls of Soil-Cement with the Addition of Ground Ceramic Waste, Revista Brasileira de Engenharia Agrícola e Ambiental, Vol.7, No.3, p.552-558.
[2]. S. Karaman, H. Gunal, and S.Ersahin, (2006), Assessment of Clay Bricks Compressive Strength Using Quantitative Values of Color Components, Construction and Building Materials: Vol. 20 pp. 348–354.
[3]. G. Cultrone, E. Sebasti, and M.J. de la Torre, (2005), Mineralogical and Physical Behavior of Solid Bricks with Additives, Construction and Building Materials: Vol.19 pp. 39–48.
[4]. P. Lopez-Arce, D. Benavente, and J. Garcia-Guinea, (2005), Durability Improvement of Ancient Bricks by Cementation of Porous Media, The American Ceramic Society Journal, Vol. 88, No. 9, pp. 2564–2572.
[5]. R. Boynton, and K.A. Gutschick, (1990), Efflorescence of Masonry, National Lime Association, Masonry Lime Technical Notes.
[6]. X. Wei, and M.G. Stewart, (2010), Model Validation and Parametric Study on the Blast Response of Unreinforced Brick Masonry Walls, International Journal of Impact Engineering: Vol. 37, pp.1150-1159.
[7]. H.B. Kaushik, D.C. Rai and S.K. Jain, (2007),Uniaxial Compressive Stress–strain Model for Clay Brick Masonry, Current Science, Vol. 92, No. 4, pp. 497-501.
[8]. W.S. Mcnary and D.P. Abrams, (1985), Mechanics of Masonry in Compression, Journal of Structural Engineering, Vol. 111, Issue 4
[9]. H.B. Kaushik, D.C. Rai and S.K. Jain, (2007), Stress-Strain Characteristics of Clay Brick Masonry Under Uniaxial Compression, Journal of Materials in Civil Engineering, (ASCE), Vol.19(9), pp.728-739.
[10]. R. K. Roy, (2001), Design of Experiments Using the Taguchi approach, John Wiley.
[11]. R. Unal and E.B. Dean, (1991), Taguchi Approach to Design Optimization for Quality and Cost: an Overview, Annual Conference of the International Society of Parametric Analysts.
[12]. Egyptian Standards Specifications: (1756/1989 &1524/1993), "Building Brick Solid Masonry Units Made From Clay or Shale", Egyptian Organization for Standards and Quality, Cairo, Egypt.
[13]. Egyptian Code of building (204-2005), "Principle Design and Guidelines for Implementation Masonry Works, Testing Manual", Ministry of Housing and Urbanization, Housing and Building Research Center, Cairo, Egypt.
[14]. U. Eşme, (2009), Application of Taguchi Method for the Optimization of Resistance Spot Welding Process, The Arabian Journal for Science and Engineering, Volume 34, No. 2, pp. 519-528.
[15]. S. M. Holt, (2011), Effect of Processing Parameters on Bond Strength and Effective Plasticity in Al_2O_3-TiB_2 Composites, M.Sc. Thesis, Materials Science and Engineering, faculty of the Virginia Polytechnic Institute.
[16]. S. Rama Rao and G. Padmanabhan, (2012), Application of Taguchi Methods and ANOVA in Optimization of Process Parameters for Metal Removal Rate in Electrochemical Machining of Al/5%SiC Composites, International Journal of Engineering Research and Applications (IJERA), Vol. 2, Issue 3, pp. 192-197.
[17]. B. Berginc, Z. Kampuš, and B. Šuštaršič, (2006), The Use of the Taguchi Approach to Determine the Influence of Injection-Moulding Parameters on the Properties of Green Parts, Journal of Achievements in Materials and Manufacturing Engineering, Vol. 15, Issue 1-2.
[18]. M. Ghazy, (2012), Effect of Using Mortar Interface and Overlays on Masonry Behavior by Using Taguchi Method, ACI Materials Journal, pp. 509-516.