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Modelling of Clay Ceramic Paste Composition in Production of Ceramic Tiles

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Abstract

Ceramic materials are the most popular materials for different types of buildings. However, many obstacles meet the process of ceramic industry.

Therefore, the aim of this paper is finding a new methodology to achieve the best mixture of ceramic paste depending on geotechnical properties of clay (Atterberg limit & grain size), thus by trying different mixtures and then comparing the specifications of a final product. Many mass formulations were tested in the laboratory at the optimal processing conditions (applied pressure and firing temperature). Then specific software is designed through modeling the experimental results for normalizing. The new software program is clay-ceramic pastes (CCP). CCP evaluates the raw material and checks the appropriate one for the desired final product.

This research will contribute to minimize the random choices of raw materials and saving time through reducing the number of trials that were spent to reach to optimum formulation of ceramic paste.

Keywords: Clay, Ceramic paste, Modeling, Ceramic specification, Atterberg limits.

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1- Introduction:

Recently, a large demand has been placed on ceramic materials which are the most versatile branch of materials [1] and most commonly used engineering materials [2]. The raw materials that are used in traditional ceramics could be classified into three groups: clay, silica, and feldspar [3].

Zanatta et al. [4].contribute to the sustainable development of ceramic products, and according to huge quantities of ceramic materials and thus wastes of these industry Ambrose et al., [5] discuss the usage of these wastes in production of concrete. Soldati et al. [6] research in in improving making by developing technology and optimization, the ceramic tile. Olhager and Rapp [7] present the great potential of OR (operation research) and techniques in the field of manufactory planning and control. Tian and Hu [8] assure that current world ceramic industry is diversified so there is a huge challenge to the development of ceramics. Ribas et al. [9] conclude that new research that considers several constraints and several criteria is needed in order to diminish the gap between the real-world industrial scheduling problems and their treatment in science. Ruiz and Vázquez-Rodríguez [10] also reach the same conclusion: realistic settings are seldom studied. Many aspects make the automatic control for the industry of ceramic tiles is complex, such as structural nature of the ceramic product, and the wide variety of products that are required [11]. However, it is so important and very economic strategy to organize the best industry process. Therefore, this paper focuses on developing the industry process of ceramic tile by using the appropriate parameters of clay soil and then modelling the results for normalization.

2 – Materials and Methods:

2-1 Materials:

Clay soils are the primary materials for ceramics industry. In Syria, most of ceramics tile are produced from clay sand and phosphate sodium. There are many locations of clay soil around Syria but the most common resources for ceramic industry are: al-Moukharram, Mkemen, al-Teyyas, Rkhemeh, Zukara, Kfer Yabous, Ariha, Der al Adas. The soil samples was chosen from four locations: al-Mokharam, Kfer Yabous, Zoukara and Mkemen. In addition, three components are added: sand from al-Qareeten, sodium feldspar and dolomite. Table1 presents the mineralogical composition of studied soils that were be done by XRD technique [12], and Table 2 presents chemical composition by (XRF) technique [12]. Fig.1 present grain size distribution for one of soil sample (Mkemen) according ASTM D 422, and Table 3 presents Atterberg limits for the same sample according ASTM D 4318.

Table1: Mineral composition for raw materials [12]

	Kfer	Mokharram	Zukara	Mkemen
Chlorite			x	x
Smectite/Kaolinite	x		x	
Illite/Muscovite		x	x	x
Montmorillonite		x		
Quartz	x	x	x	x
Calcite ($CaCO_3$)	x	x	x	x
Kaolinite/Halosyte	x	x		x
Potasium Feldspar			x	x
Iron Oxide	x	x		
Titanuim Oxide		x		
Gypsum	x	x	x	x

Table 2: Chemical composition for raw materials [12]

Locations of Soil	**Average chemical composition**									
	L.O.I.	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	SO_3
Kfer	0.17	1.84	0.05	1.13	0.29	0.49	3	11.82	76.61	9
Mokharram	0.3	0.84	0.17	2.95	1.58	10.14	6.09	16.33	47.9	13.66
Zukara	0.11	0.92	0.18	3	1.75	2.94	7.79	20.07	53.89	9.55
Mkemem	8	0.75	1	3	2	6	5.5	20	47	12
Sand	2.75	93.38	0.94	0.28	2.3	0.17	0.19	0.04	0.06	
Feldspar	0.34	69.38	17.71	0.13	0.69	0.1	0.26	10.17	0.29	
Dolomite	43.61	0.56	0.05	0.06	55.53	0.16	0.006	0.06	0.01	

Table 3: Atterberg Limits for Mkemen sample [13]

Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
47.44	**31.73**	**15.71**

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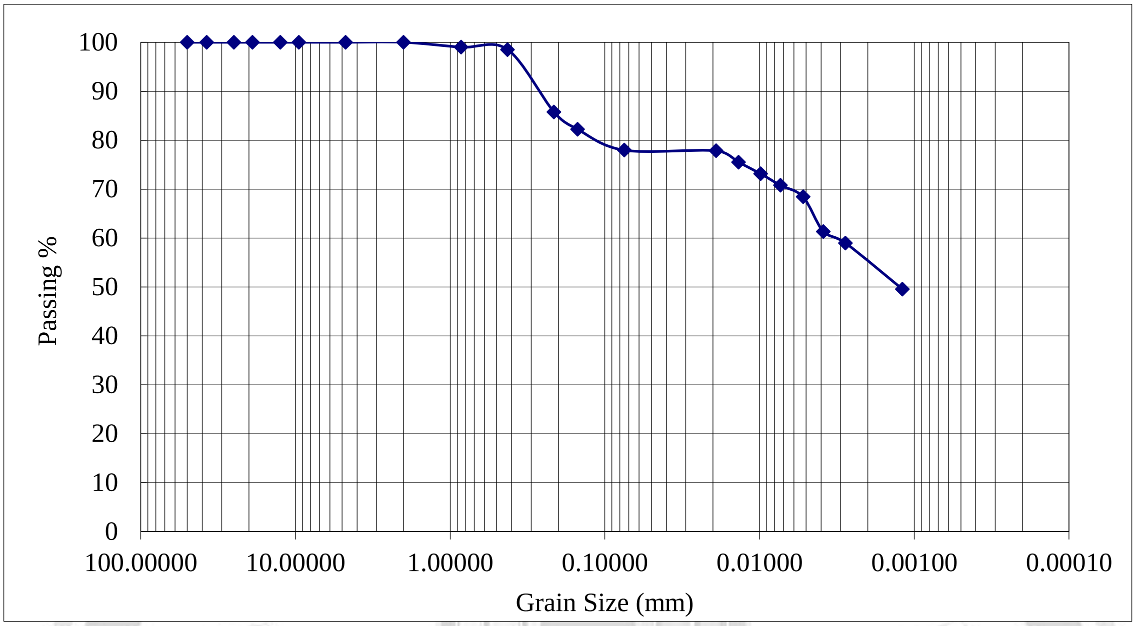

Fig.1: Grain Size Distribution for Mkemen sample [13]

2-2 Methods:

The methodology of this research could be divided into two main stages: Experimental stage, Simulation and Modelling Stage.

2-2-1 Experimental stage:

This stage covers two main steps: preparing raw materials and forming the ceramic sample. Through preparing ceramic paste, the same components are used but, with different percentages. After reviewing many formula of ceramic pastes [14] only three mixtures are presented in this paper as in Table 4.

Preparation of raw materials for manufactory:

- Prepare the main components of ceramic paste: clay soil, sand, sodium feldspar.
- Weigh the required quantity from each material, dry it and then put all materials to crush it in the lab mill adding 40% of water for 15min.
- Kept the mixture for 48 hours in closed container in order to assure that moisture content is equally distributed in the mixture, then the mixtures are dried and re-crushed.

Sample forming:

The ceramic samples are shaped in a mold with dimensions 20*10*0.5 cm by pressing in hydraulic press 22.6 MPa, as shown in Fig. 2. Then it is dried until reaching to a moisture content ranging between (5-6)% as shown in Fig.3. After drying and weighing, it is fired in electrical laboratory furnace at temperature 1120°C for 37 min. Then it is cooled to be ready for measurements.

Table 4: Compositions for first group of pastes

Material	Paste No.1	Paste No.2	Paste No.3
Mkemen	10	15	20
Zoukara	33	38	30
Kfer	33	20	25
Dolomite	6	5	6
Sand	2	6	4
Feldspar	16	16	15
Pressure (MPa)	**22.6**	**22.6**	**22.6**
Powder moisture (%)	**6**	**6**	**6**
Green Flexural (MPa)	0.82	0.87	1.21
Dry Flexural (MPa)	1.87	1.89	2.36
Firing Temperature	1120/37	1120/37	1120/37
Shrinkage	0.55	0.29	0.55
Water Absorption	16.36	17.11	16.57
Fired Flexural (MPa)	33.66	34.02	42.48

Fig.2: Samples preparation by Hydraulic Press

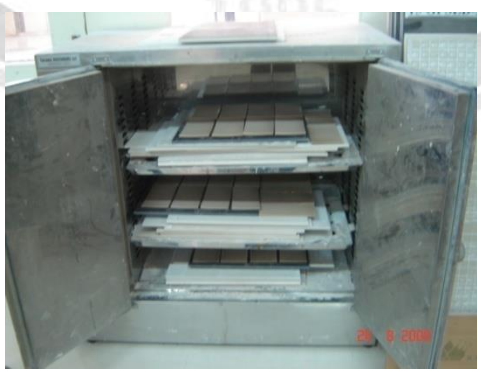

Fig.3: Samples in Dryer

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Results of experimental tests:

The physical and mechanical tests for ceramic samples are done according the standards ASTM C67[15], such as water absorption, flexural strength (green, dry and fired one), shrinkage as in Table 4. It is obvious from the values of Table 3 that there are unlimited choices for composition percentages and each has its different limits even if the other conditions is fixed such as the firing temperature, pressure value and initial moisture.

By deep analyzing for the results in Table 4, when the percentage of clay soil from site Mkemen (as example) increases the flexural strength increases and water absorption decreases after 15% of Mkemen soil as clear in Fig. 4, however, the shrinkage increases, which mean that the addition of Mkemen will improve the specifications if the shrinkage limit still within the standards. Take in consideration, this percentage could not represent the accuracy because there are more than one components in one paste.

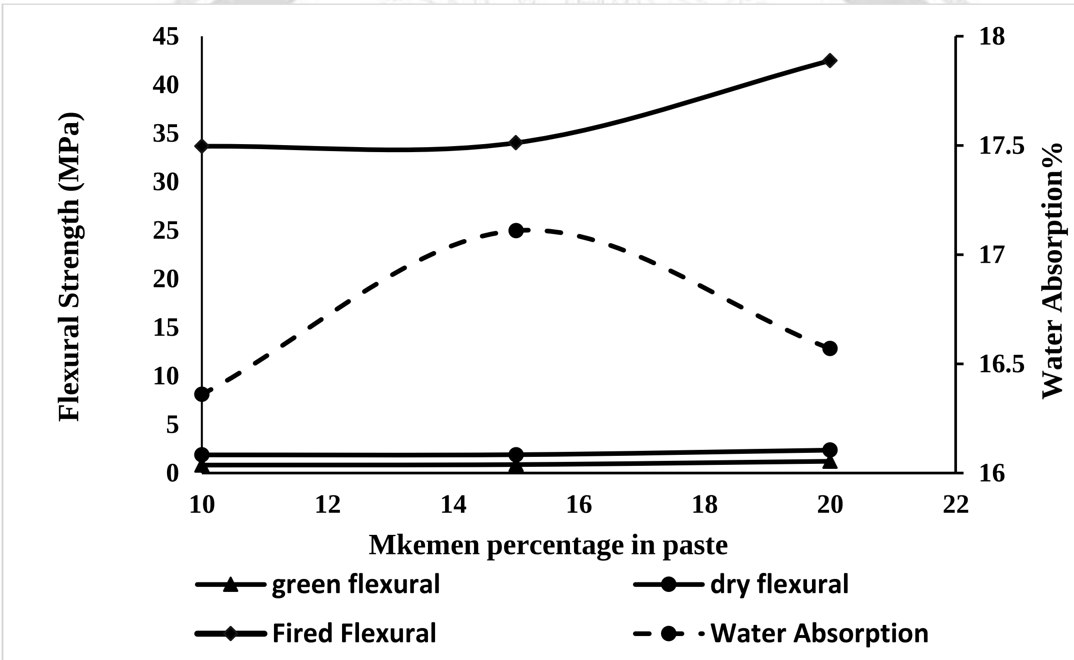

Fig.4: Effect of the percentage of Mkemen soil on flexural strength and water absorption

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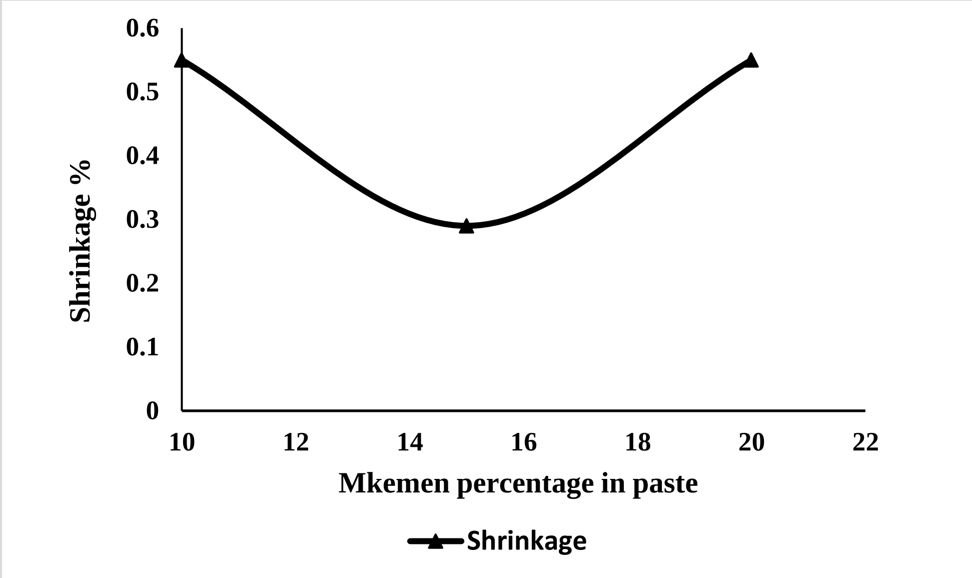

Fig.5: Effect of the percentage of Mkemen soil on shrinkage

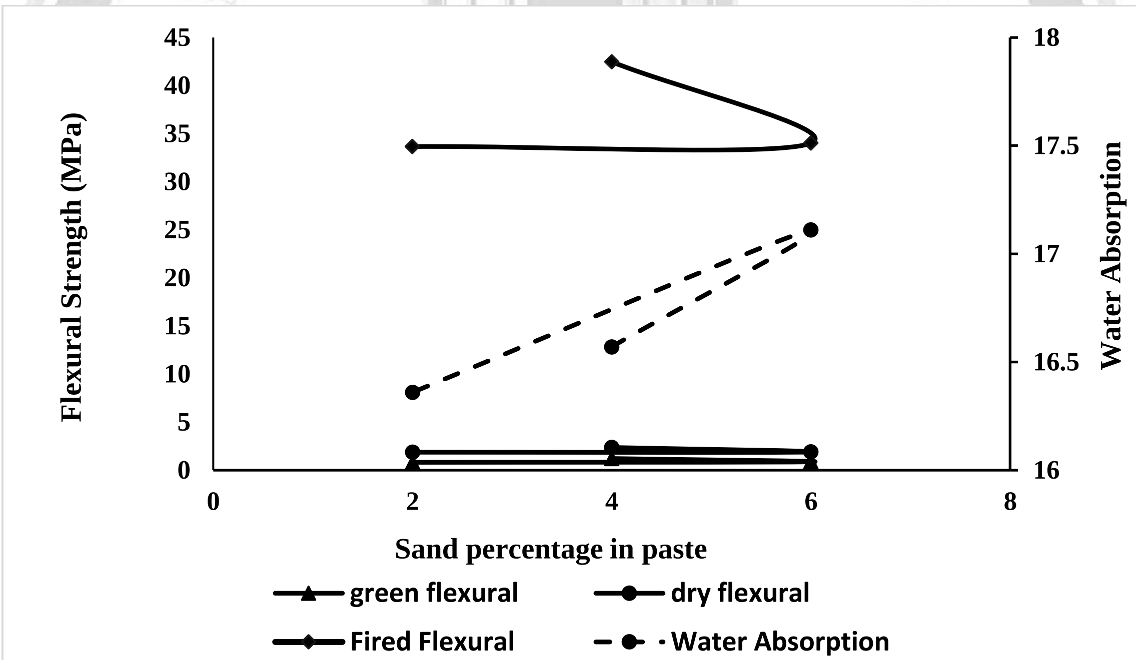

Fig.6: Effect of the percentage of sand on flexural strength and water absorption

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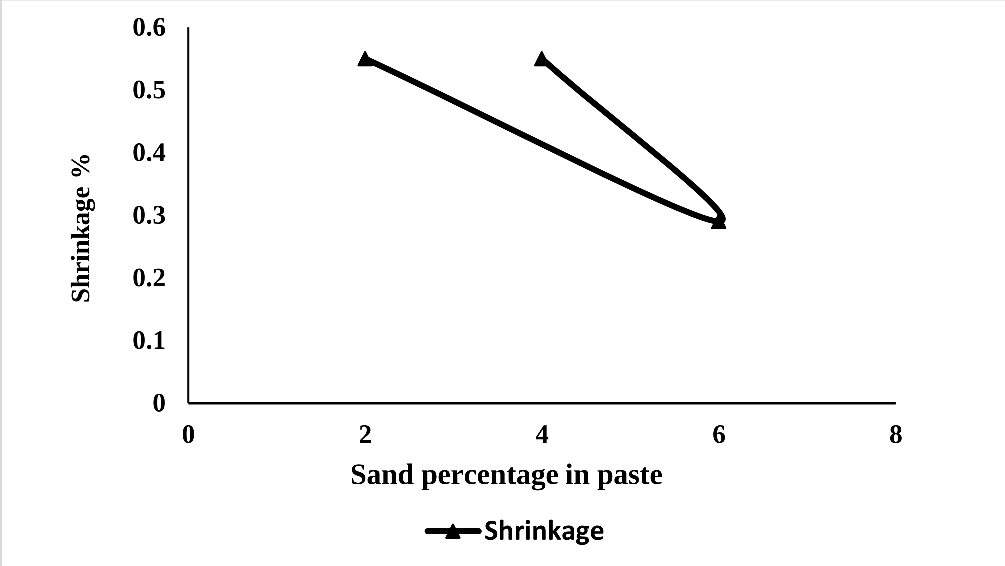

Fig.7: Effect of the percentage of sand on shrinkage

On the other hand, from Fig6 & Fig.7, there are no clear relations between the sand additives and each of flexural strength, water absorption or shrinkage. This reflects the need of many trials of paste compositions to find the ideal composition.

From this point of view, a vital step in improving the industry process is looking for modelling the paste composition which provide the manufacturer with best choices. Therefore, a software Ceramic Clay Paste (CCP) is designed in order to save time, to predict the suitability of available clay soil as raw material for ceramic industry and achieve the international specifications.

2-2-2 Modelling stage:

Scope of CCP:

Simulation modeling is often used by users to quantify and observe behaviors of processes by analyzing and comparing alternatives [16]. Smart Manufacturing (SM) requires the collaboration of advanced manufacturing capabilities and digital technologies to create highly customizable products faster, cheaper, and greener. According to NIST: "Smart Manufacturing Systems (SMS) should enable manufacturers to easily and rapidly respond changing demands and conditions, reconfigure factory production to optimize system performance, deal with uncertainty and learn from past experience for continuous improvement" [17]. So, the programing in this paper try through correlating between essential raw materials and final products to enhance SM in ceramic industry. It is designed to relate the initial indexes of raw materials that could be available from laboratories tests and the technical specifications of final product of ceramic material. By consequence, when the specifications of final product become known (output), the manufacturer could deiced if the raw materials (input) are accepted for this industry or not. This prediction before beginning of industry process will minimize the huge numbers of trials that always be done in factory to reach the most appropriate ceramic composition. This process is valid regardless of the type or composition or structure of clay soil.

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Program steps:

Fig.8 illustrates the initial window of program. Through this window all information about clay soil could be input.

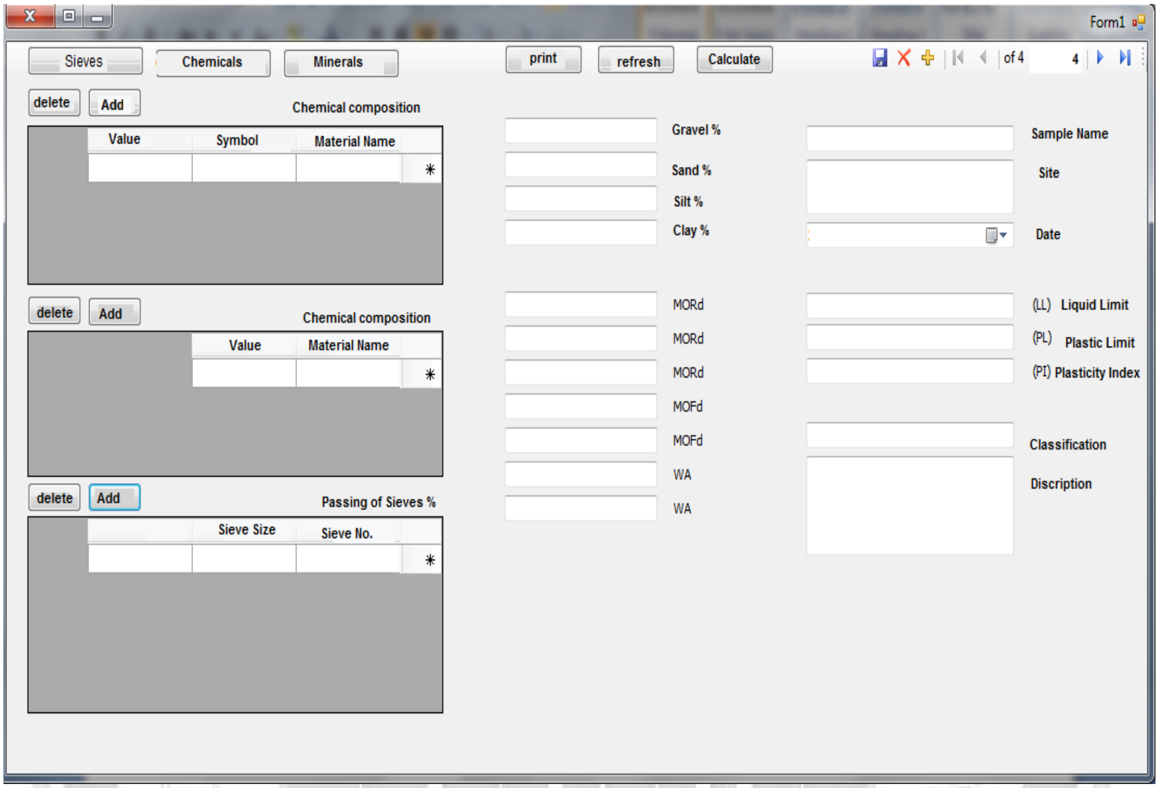

Fig.8: Initial window of program

beginning from the identity of soil sample: name, location, depth, date; chemical composition of soil sample; mineral composition; passing percentage of sieves in sieve analysis test (that will be done in soil laboratory); Atterberg limits of soil (liquid limit, plastic limit). Then in Fig.9, it is obvious that program calculate and present the results for the soil sample such as: (Gravel % - Sand % - Silt % - Clay %) which results from input of sieve analysis in Fig.1. In addition, plasticity index will be calculated resulting from Liquid limit and Plastic limit, thus the soil will be classified according USCS as from Table 3.. Next, all specification of final ceramic

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product that is assumed to be made of that soil sample will be available which are: MOR_D (modulus of rapture for dry sample) MOR_F, (modulus of rapture for Fired sample) WA% (water absorption).

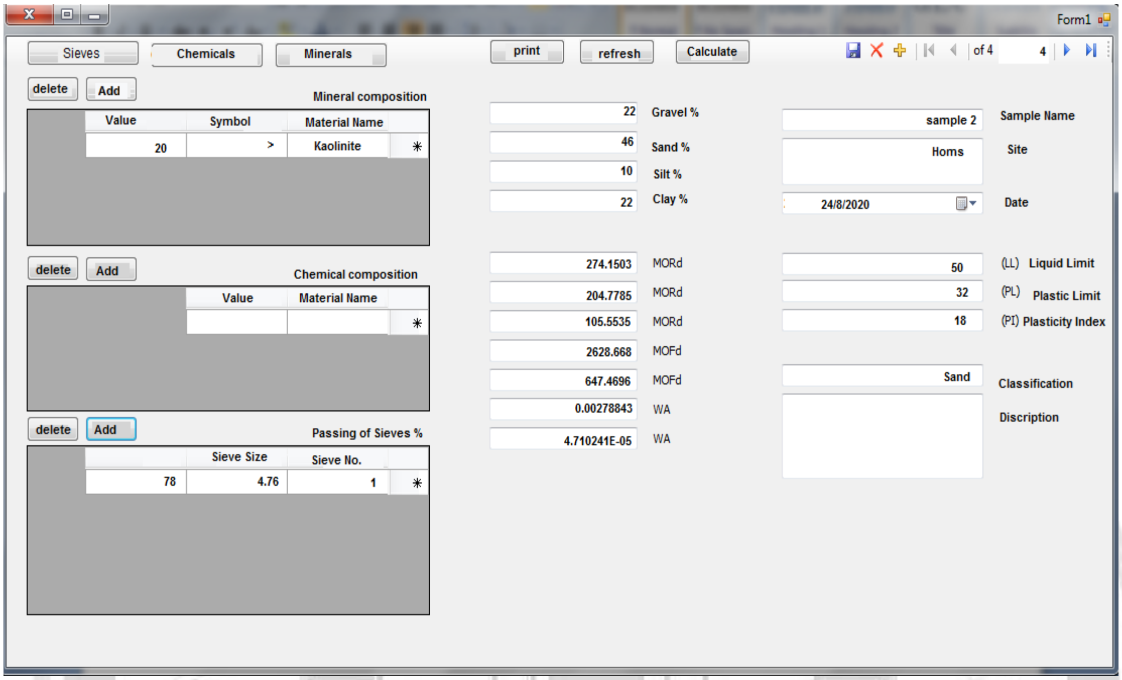

Fig.9: Final window of program

Then, according international norms, program clarify if strength value of ceramic sample is accepted or not, and classifies ceramic sample in appropriate group depending on water absorption percentage.

Fig.10 illustrates how could be input the mineral composition of soil sample. These information could be available after XRD (X-Ray Diffraction) tests for soil sample. Where, the chemical composition of soil sample after XRF test is provided as in Fig.11.

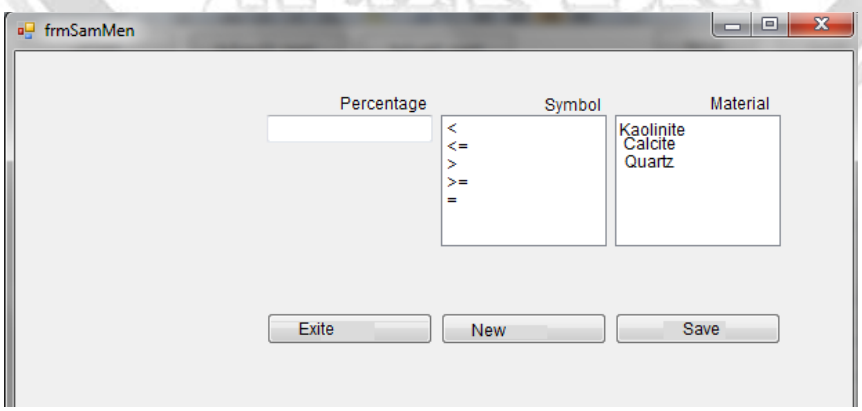

Fig.10: Mineral composition input

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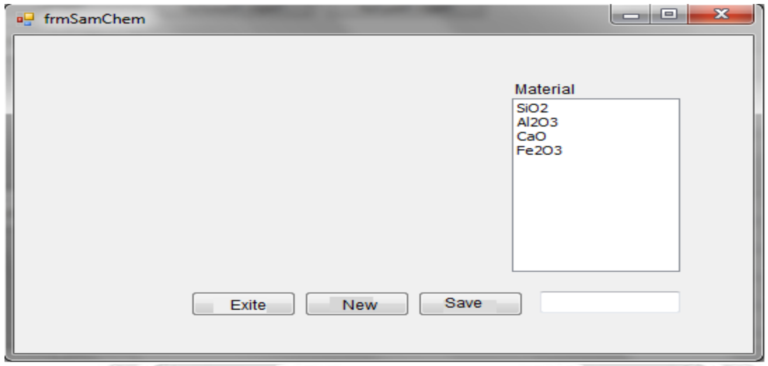


Fig.11: Chemical composition input

In Fig. 12, sieve numbers and opening are used for grain size distribution information of soil sample. After finalizing sieve analysis laboratory test, the passing % from each sieve could be input through th is window.

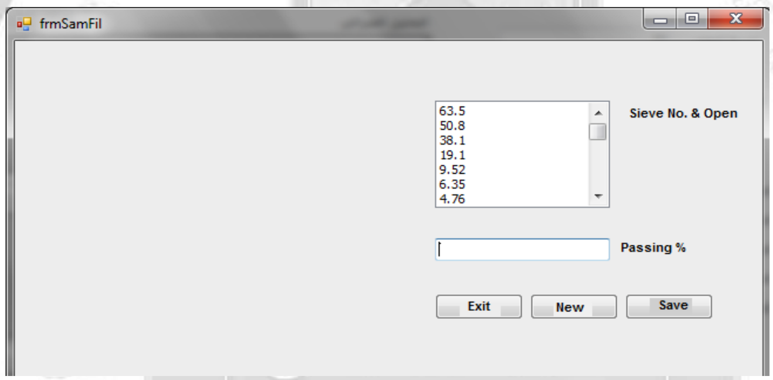
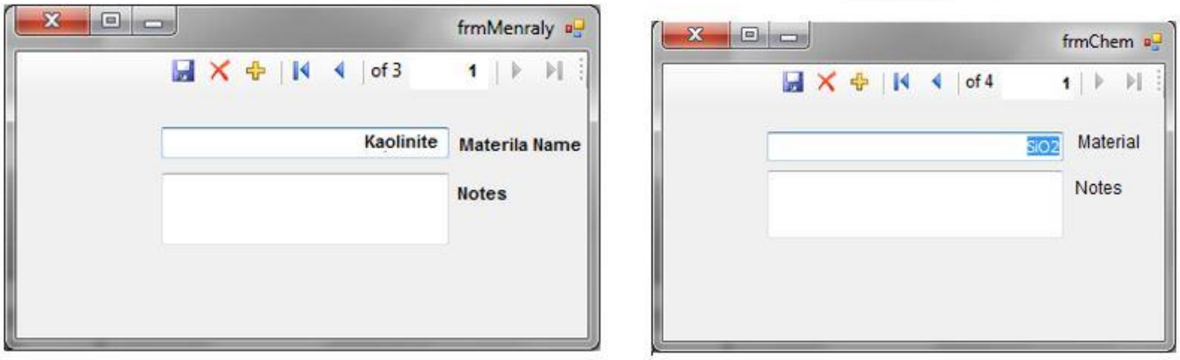


Fig.12: Grain size Distribution Input

Sometimes, after completing the input, some mistakes could be found in values so, the program validate the modification through the following steps. In Fig 13-a, it is obvious that could be modified the type of clay mineral by example, and in Fig. 13-b, could be modified the chemical composition oxides



(a) (b)

Fig.13: Mineral composition modification

Finally, Fig. 14 presents the database that is used to build CCP program.

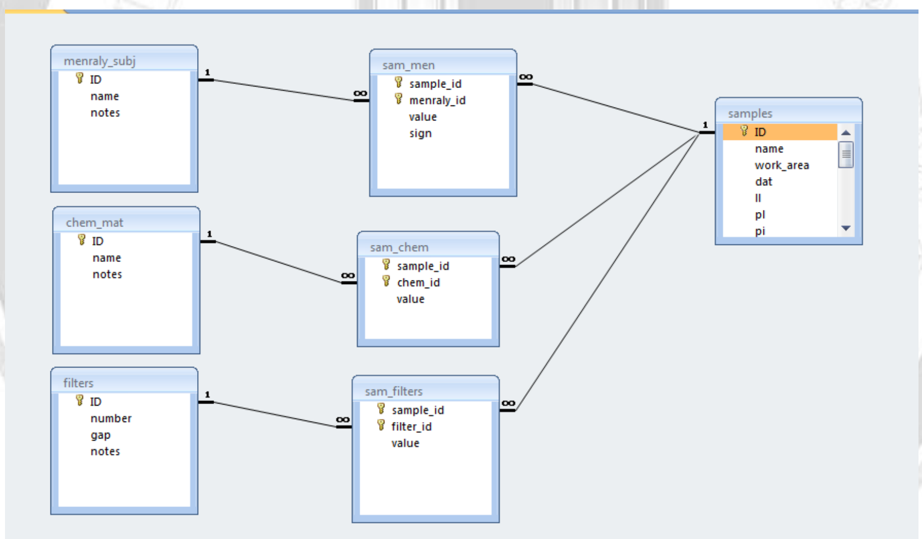


Fig.14: Database of Program

3- Conclusion:

It is so essential to find relation between different properties of engineering materials to improve the industry process. CCP software is a trial to relate the geotechnical properties of clay which is a main component of ceramic tile, with the specifications of final product. It could be conclude from the above results:

- The final properties of composite materials depend on the initial properties of raw components.
- The improving of manufactory process mean save time and develop the final products, and this the main goal of automatic control.

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- Ceramic tile industry need many trials of pastes to reach the best product because it consists of different types of raw materials, even under the same conditions of pressure and temperature.
- Geotechnical properties of clay soil affect deeply on the specifications of ceramic tile, which is not covered from most of ceramic factories before.
- CCP software save time and develop the industry process of ceramic tile and could serve many manufacturers.

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نمذجة لتركيب الخلطات السيراميكية الغضارية في تصنيع البلاطات السيراميكية

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الخلاصة:

تعتبر المواد السيراميكية من أكثر المواد استخداماً في أنواع مختلفة من الأبنية، إلا أن هناك العديد من المشكلات والعراقيل التي تواجه صناعة المواد السيراميكية.

ولذلك، هدف هذا البحث إلى إيجاد طريقة جديدة لايجاد المزيج الأفضل للعجينة السيراميكية حيث تعتمد هذه الطريقة على الخواص الجيوتكنيكية للغضار (حدود أتربرغ والتدرج الحبي للجزيئات). تم ذلك بتجريب عدة أمزجة مختلفة ومن ثم مقارنة المواصفات الفنية للمنتج النهائي. حيث استخدمت عدة صيغ لتركيب الخلطات السيراميكية وتم تطبيقها مخبريا تحت شروط مثالية وموحدة (الضغط المطبق ودرجة حرارة الشوي). بعد الحصول على بيانات تجريبية تم نمذجتها والاستفادة منها لتصميم برنامج حاسوبي جديد هو CCP (خلطات سيراميكية غضارية). يقيّم برنامج CCP المواد الأولية المستخدمة ويختبر أكثرها تلاءماً للحصول على المنتج النهائي المطلوب.

يساهم هذا البحث في توفير الوقت واقتصاد الزمن عبر تخفيف الخيارات العشوائية للمواد الأولية وأيضاً تخفيف عدد المحاولات التي تُنفَّذ في المصانع حتى الوصول إلى المزيج الأمثل للعجينة أو التركيب السيراميكي.

الكلمات الدالة:-الغضار، العجينة السيراميكية، النمذجة، المواصفات السيراميكية، حدود أتربرغ.

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