ESTABLISHING THE MODEL FOR PREDICTING THE DURATION OF THE MAIN STAGE OF DRYING GREEN MASONRY PRODUCTS

Miloš Vasić[1] & Zagorka Radojević [1]

„Institute for Testing of Materials“, 43 Bulevar vojvode Mišića, 11000 Belgrade, Serbia

Corresponding author: Miloš Vasić, milos.vasic@institutims.rs

Abstract: In this paper it is presented the researching results for drying behavior of the drying green masonry products from the site Banatski Karlovac. Raw masonry clay was characterized. Testing bodies were prepared by hand in special mold, from the classically prepared raw material after its homogenization and moistening. Classical procedure of raw material processing was carried out by milling in perforated rolls and milling on differential rollers up to grain size not exceeding 1 mm. Experimental investigation of drying test bodies were performed in the laboratory recirculation dryer. The mathematical dependence of the duration time for the main stages of drying, with temperature, humidity and velocity of drying medium was modeled. The obtained model has practical significance because it can be used to optimize the drying process of masonry products in industrial conditions. This model is tested in factory „Naša Sloga“, Kovin.

Key words: main stages of drying, masonry product, mathematical model.

1. INTRODUCTION

There are numerous literature data(1,2,3) about preparations for the production of raw materials in the masonry industry, their characterization, determination of optimal raw material composites, determination of technological parameters of the raw materials during shaping, drying and firing. Mechanical activation (4, 5) is a process of increasing the reaction capacity of materials in which the active material remains chemically unchanged. Mechanical activation leads the material to excited state when it may be potentially capable to move from this state to a stable state. The way in which change will take place from the excited state to a stable state depends, among other things, from the way of mechanical activation, the nature of the active material and the presence of other chemical components to which the active material has a chemical affinity. In the technological process of masonry elements production, the phase of drying is the part in which all the disadvantages of previous operations come to an expression. Inadequate mineral composition of the raw material mixture, insufficient or too moisture content, poor homogenization of mass, insufficient vacuum in the vacuum presses, as well as a damage occurred in the transport to the dryer significantly affect the quality of drayed products(6). In this paper, the planning technique of full factorial experimental design was used in order to establish the dependence of the duration time for the main stage of drying as a function of the drying medium parameters (the temperature, humidity and velocity).

2. GENERAL INFORMATION

2.1 Experimental conditions

In experimental work a representative sample of the masonry raw material, from Banatski Karlovac, was used. The raw material was first dried in laboratory dryer at a temperature of 60^0C, and then after cooling to room temperature, was milled down in lab perforated rolls mill. It was mill down about 50 kg of raw material. From this amount, about 10 kg is identified and subject to further classical preparation (the amount which in further experimental work presents a representative sample), which precedes the formation on the vacuum presses. Thus prepared sample in further experimental work was treated as inactivated sample and carried the name - the sample A. On the basis of data from the literature(7,8,9), which treats the problem of mechanical activation of clay material, it was concluded that the best results cud be achieved if the activation is carried out in 220 rotation per minute and the pellet mass compared to the entered weight of material as a ratio 1:3.75. The same ratio was used in the mechanical activation of examined masonry raw material. For samples A and mechanically activated samples B, testing of technological properties relevant to the process of shaping and drying of masonry products were carried out. The determination of important parameters for the forming process of masonry products were carried out. It was measured the amount of water needed for plastic forming of masonry products and the plasticity according to Feferkorn (coefficient and the criterion of plasticity). Draying sensitivity of the examined samples was determined by recording Bigot’s curves of the barelatograph device. In further experimental work, laboratory samples dimensions 120x50x15mm, formed by hand from starting raw materials A and mechanically activated raw material B in molds made specifically for this purpose, were used. On the basis of mathematical models the experimental plan in which the parameters are defined for the process of drying (temperature, humidity and speed of drying medium), was set up. The display of experimental condition values that are related to the drying medium are shown in Table 1.

Table 1. Experimental condition values of temperature, humidity and speed of drying medium

Num.	Air velocity	Air temperature	Air humidity
1	1	40	60
2	3	40	60
3	1	80	60
4	3	80	60
5	1	40	80
6	3	40	80
7	1	80	80
8	3	80	80

Two series of experiments were performed using laboratory samples with a starting raw material and samples of raw material B (the starting raw material that was mechanically activated for 30 minutes). Within each series the repetition of experiments were carried out, under the same conditions, so that the total number of experiments was 16. During the experiment the given values of drying parameters were maintained on a constant level. The behavior investigation of the clay samples under the drying process were done in the form of registration the linear shrinkage and weight changes of created masonry products during drying in the specially constructed laboratory dryer.

Laboratory recirculation dryer provides:

- regulation of air temperature for drying in the limit of 0-125 C° C with accuracy 0.2 ± C°
- regulation of relative humidity of 20-100%, with accuracy of 0.2%
- speed regulation of the media from drying from 0-3, 5 m/s, with accuracy 1%.
- monitoring the samples mass loss of the masonry products which are dried in the range of 0-2000g with 0.01 g accuracy
- tracking of linear shrinkage in the range of 0-23 mm with accuracy of 0.2 mm
- Continuous time monitoring and recording the values of temperature and humidity of drying medium as well as collecting the linear shrinkage of the masonry samples during drying.

2.2 Characterization of raw masonry clay

Characterization of raw masonry clay was done by establishing granulometric and chemical composition (Table 2. and fig. 1.), DTA and TG analysis (fig. 2.), dilatometric testing (fig. 3.), X-ray analysis (fig. 4.) and the size distribution of particles (fig. 5).

Table 2. Results of chemical analysis

Composition	%
Loss ignition on 1000^0C	11.71
SiO_2	53.23
Al_2O_3	13.64
Fe_2O_3	5.34
CaO	7.50
MgO	3.59
SO_3	0.00
S^{2-}	0.00
Na_2O	1.24
K_2O	3.42
MnO	0.091
TiO_2	0.60
Summary:	100.36
Insoluble rest:	71.13
Loss of moisture	2.04

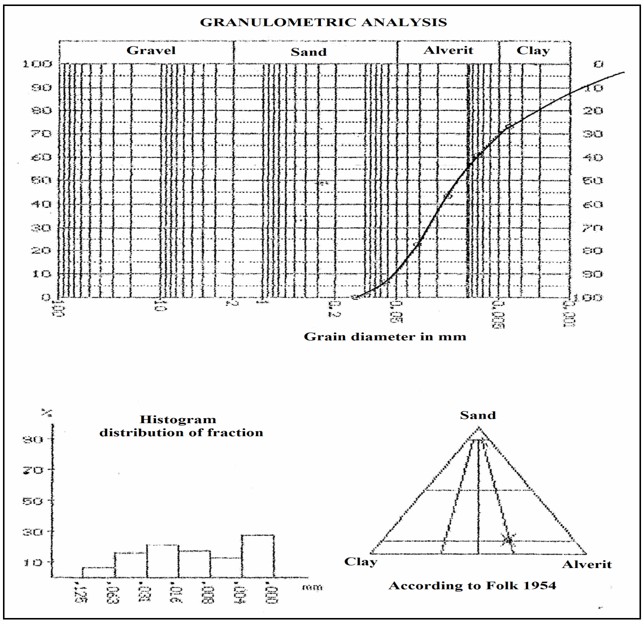


Fig. 1. Granulometric histogram

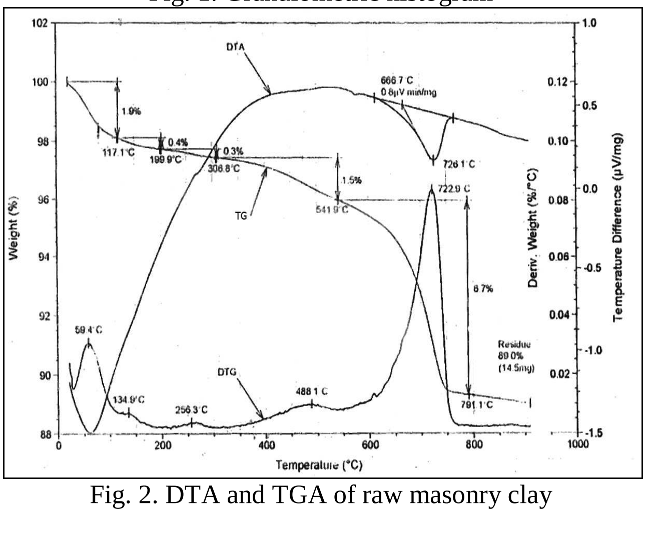


Fig. 2. DTA and TGA of raw masonry clay

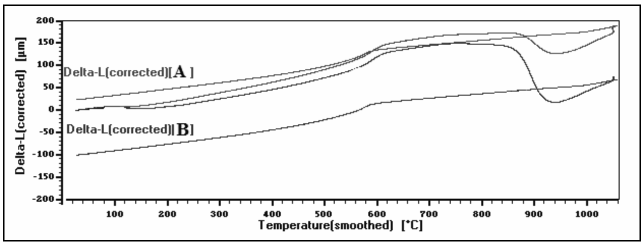


Fig. 3. Dilatometric curves of samples form raw masonry clay A and B

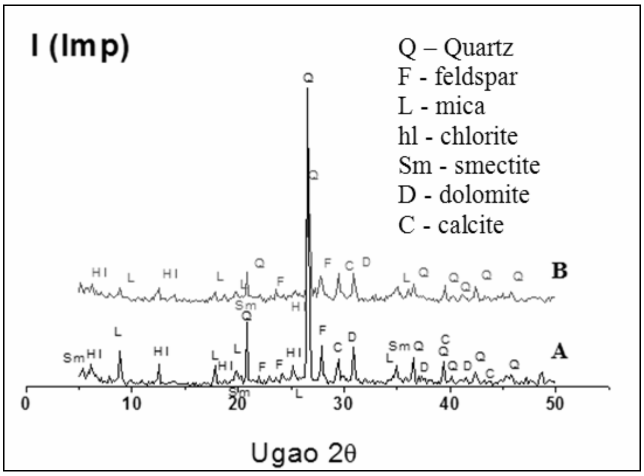


Fig. 4. X- ray of samples form raw masonry clay A and B

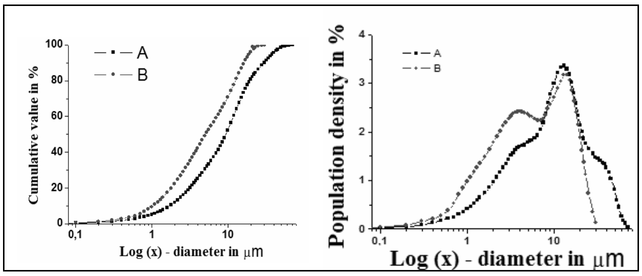


Fig. 5. Particles size distribution of starting masonry raw clay and mechanically activated masonry raw clay

2.3 The results of the technological characteristic of the sample before and after mechanical activation

The properties of the samples during the formation of samples A and B and the properties of samples in the process of drying were given in table 3.

Table 3. Properties of the sample during the process of forming and process of drying

Forming process		Sample A	Sample B
The amount of water for forming in (%)		20.64	30.71
Plasticity according to Feferkorn	Coefficient of plasticity	27.2	35.38
	Plasticity criteria	Good plasticity	High plasticity
Drying process		Sample A	Sample B
Bigot's curve	Shrinkage at critical point (%)	5.12	7.67
	Water loss at critical point (%)	9.62	17.37
	Drying sensitivity	Sensitive	Highly sensitive

2.4.The drying results for samples A and B

On the basis of experimental data for the drying conditions in each experiment, the humidity values in the critical point were calculated. These values are shown in the table 4.

Table 4. Experimental results for a sample A and B

Experiment		Sample A	Sample B
		$T_{main\ stage}$ min	$T_{main\ stage}$ min
1/40/60	1	201	411
	9	277.4	392
Mean value		*239.20*	*401.5*
3/40/60	2	105	181.63
	10	104	181.00
Mean value		*104.50*	*181.35*
1/80/60	3	142	180
	11	140	200
Mean value		*141*	*190*
3/80/60	4	104	127
	12	77	109
Mean value		*90.50*	*118*
1/40/80	5	499	612
	13	432	587
Mean value		*465.50*	*599.5*
3/40/80	6	413	423.15
	14	350	404.55
Mean value		*381.50*	*413.85*
1/80/80	7	240	369
	15	260	378
Mean value		*250*	*373.50*
3/80/80	8	167	200
	16	200	200
Mean value		*183.50*	*200*

3. ANALYSIS AND DISCUSSION OF RESULTS

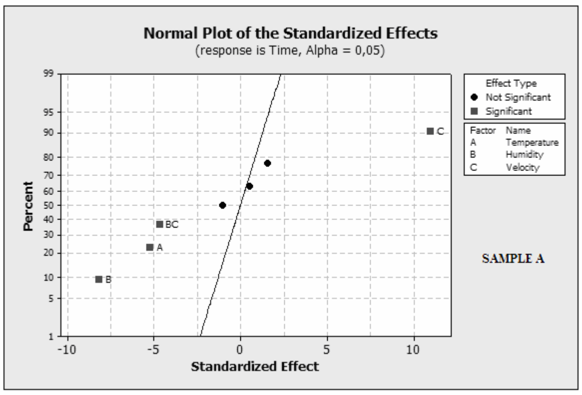
On the basis of chemical analysis can be concluded that this is a usual masonry raw material with a relatively low content of aluminum oxide, a relatively small content of clay minerals and feldspars and increased carbonate content. Granulometric histogram is protractedly unimodal with a mild drop to the left side. Dominant size fraction is in the interval of 0,001-0,004 mm. Sediment was slightly sort with an average particle size of 0,02 mm. Based on the analysis of DTA / TG diagrams for starting masonry raw material can be assumed the mineralogical composition of raw materials or in other words that it was quartz, micas, montmorionit masonry raw material with a certain content of dolomite and calcite. Dilatometric curve of mechanically activated masonry raw materials shows changes in relation to the starting dilatometric masonry raw materials curve. From the fig. 3. it can be seen that in the case of mechanically activated samples B the interval in which the linear shrinkage occurs during firing of masonry clay products is decreased for about 60^0C in relation to the starting samples A. On the basis of X-ray analysis it can be concluded that the most common mineral is quartz.

From layer silicates occurs: mica, chlorite and a little smectite. Feldspars from the group plagioclase and the group of carbonate minerals: calcite and dolomite were also present while the presence of amphiboles was in traces. The results of particle size distribution indicate that in the case of inactivated raw clay material the highest proportion of clay particles was concentrated in the vicinity of values in diameter of 15µm while in the case of activated clay raw material clay particles concentrate in the vicinity of the two diameter values at diameter 2.5 and 8.0µ m. On the basis of carried out investigations it can be noted that due to mechanical activation by milling the increase of the plasticity coefficient is happening. Inactivated sample from raw material A is classified in the group of sensitive raw material for drying. It was noted that mechanical activation affects and change the draying sensitivity of products which become more sensitive to drying process.

The values of time for the main stage of drying for different temperature, relative humidity and velocity of drying medium were experimentally determined. These experimentally determined values were inputs for the mathematical model that represents the dependence values of time for the main stage of drying in a relation with drying medium parameters (temperature, relative humidity and velocity) for sample A and sample B. Development of mathematical model is based on the principles of Box-Wilkinson’s orthogonal multifactorial experimental design. The calculation of the equation model and it's analyze was performed by using Minitab 15 software [(10)].

Table 4. Estimated regression coefficients for models in coded and un coded form for samples A and B

SAMPLE A – MODEL I						
Term	Efect	Coded Coefficiente	SE Coef	T	P	***Uncoded Coefficiente***
Constant		231,96	8,033	28,88	0,000	757,400
Temperature	-83,92	-41,96	8,033	-5,22	0,001	-12,820
Humidity	-131,42	-65,71	8,033	- 8,18	0,000	-7,850
Velocity	176,32	88,16	8,033	10,98	0,000	163,700
Temperature*Humidity	25,42	12,71	8,033	1,58	0,152	0,146
Temperature*Velocity	8,67	4,34	8,033	0,54	0,604	3,135
Humidity*Velocity	-75,33	-37,66	8,033	-4,69	0,002	-1,265
Temperature*Humidity*Velocity	-16,68	-8,34	8,033	-1,04	0,330	-0,042
S = 32,1306 ; PRESS = 33035,9 ; R-Sq = 96,78% ; ***R-Sq(pred) = 87,12%*** ; R-Sq(adj) = 93,96%						
SAMPLE B – MODEL II						
Term	Effect	Coded Coefficiente	SE Coef	T	P	***Uncoded Coefficiente***
Constant		309,71	2,889	107,19	0,000	1801,310
Temperature	-162,83	-81,42	2,889	-28,18	0,000	-22,151
Humidity	-178,67	-89,33	2,889	-30,92	0,000	-21,023
Velocity	174,01	87,00	2,889	30,11	0,000	-100,570
Temperature*Humidity	40,08	20,04	2,889	6,94	0,000	0,270
Temperature*Velocity	-16,74	-8,37	2,889	-2,90	0,020	5,533
Humidity*Velocity	-41,26	-20,63	2,889	-7,14	0,000	3,038
Temperature*Humidity*Velocity	-34,01	-17,00	2,889	-5,88	0,000	-0,085
S = 11,5579 ; PRESS = 4274,71 ; R-Sq = 99,71% ***; R-Sq(pred) = 98,86%*** ; R-Sq(adj) = 99,47%						



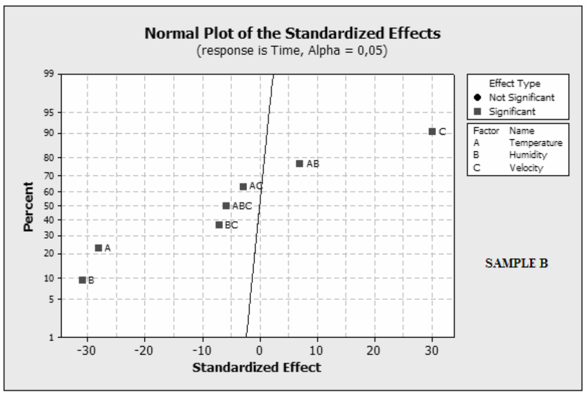


Fig. 6. Chart of normal standardized effects distribution of model for samples A and B

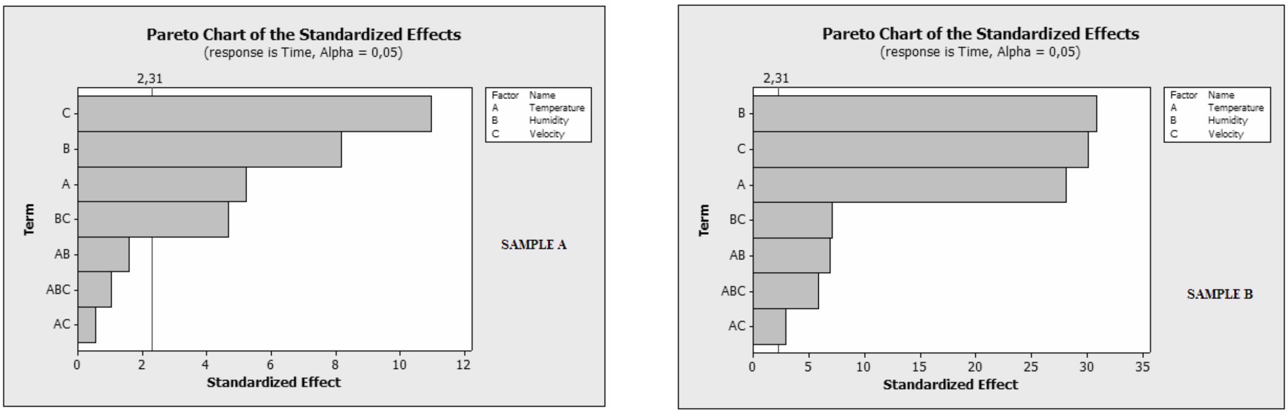


Fig.7. Paret's chart - standardized effects of model for samples A and B

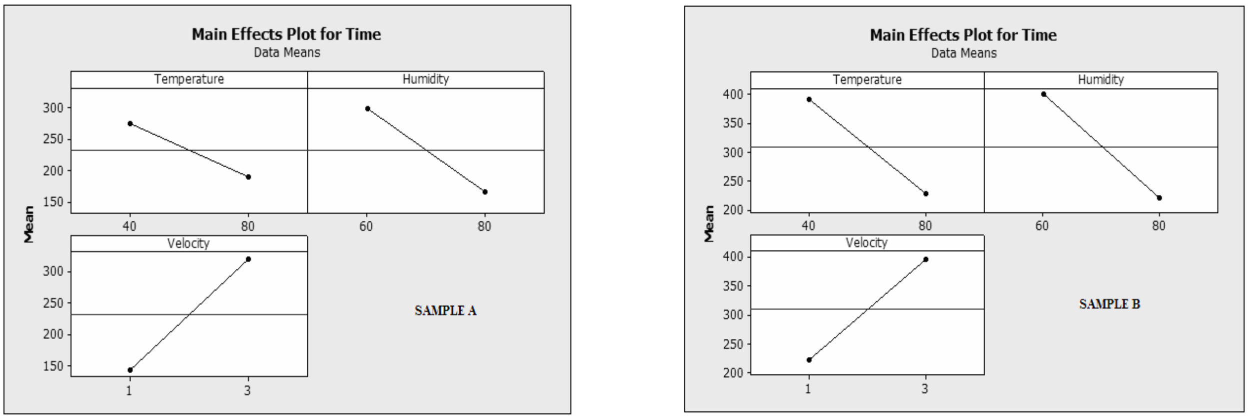


Fig. 8. Chart - main effect influence of model for samples A and B on the duration of the main stage

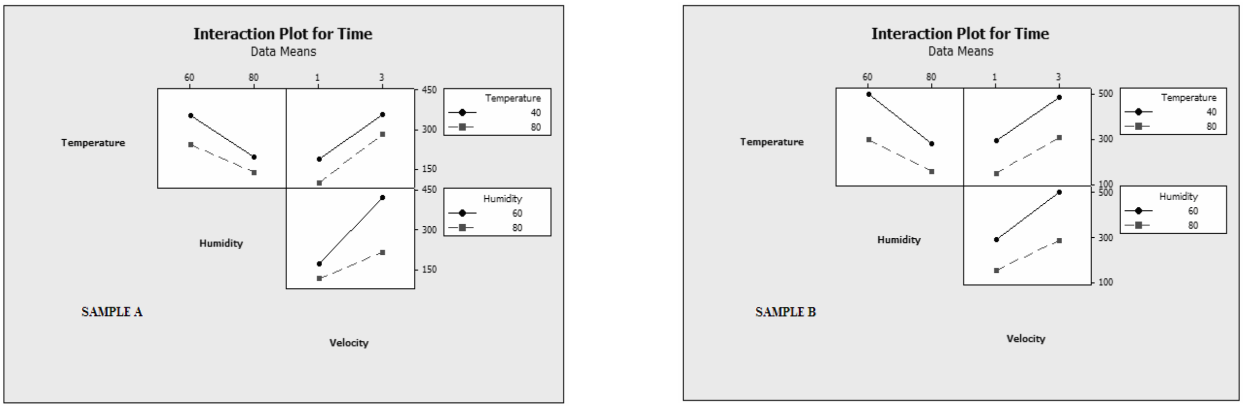


Fig. 9. Chart - mutual influence of important effects parameters of model for samples A and B on the duration of the main stage

Equation model for sample A and B are, respectively:

$$t_{main} = 757,400 - 12,820\cdot T - 7,850\cdot H + 163,700\cdot V + 0,146T\cdot H + 3,13\cdot T\cdot V - 1,265\cdot H\cdot V - 0,042\cdot T\cdot V\cdot H \quad (1)$$

$$t_{main} = 1801,310 - 22,151\cdot T - 21,023\cdot H - 100,570\cdot V + 0,270T\cdot H + 5,533\cdot T\cdot V + 3,038\cdot H\cdot V - 0,085\cdot T\cdot V\cdot H \quad (2)$$

T – temperature; H – humidity, V – velocity

Information about the adequacy of model represents the last values of the analysis processed in the software package Minitab 15 and shows that the accuracy of prediction values of response models (duration of main drying stage) is in case of samples A 87.12%, and in case of sample B 98,86%. In fig. 6. and 7. it can be seen which regression parameters in model have a statistical significances meaning.

From the analysis of the diagrams shown in the fig. 8. for the starting raw materials A, it can be concluded that the average duration time for main stage of drying for all experiments is 235 min. On the basis of slope influential lines it can be concluded that:

- A lower value for medium drying velocity causes a higher duration time for main stage of drying in relation to the case of higher value of the drying medium velocity.
- A lower value for the drying medium temperature causes a higher duration time for main stage of drying in relation to the case of lower value for drying medium temperature.
- Higher value for the drying medium humidity

causes a higher duration time for main stage of drying in the relation to the case of lower values for the drying medium humidity.

From the analysis of diagrams shown in fig. 8. for mechanically activated raw materials B, it can be concluded that the average duration time for main stage of drying for all the experiments is 305 min. On the basis of slope influential lines it can be concluded that:

- A lower value for medium drying velocity causes a higher duration time for main stage of drying in relation to the case of higher value of the drying medium velocity.
- A lower value for the drying medium temperature causes a higher duration time for main stage of drying in relation to the case of lower value for drying medium temperature.
- Higher value for the drying medium humidity causes a higher duration time for main stage of drying in the relation to the case of lower values for the drying medium humidity.

The analysis of the main effect diagrams, on the output value of model is transferred to the analysis of influential line in the diagram shown in fig. 9. for sample A and sample B. For a sample A can be concluded that:

- Duration time for main stage of drying, is decreasing when you move from the lower to the upper value for the drying medium humidity and the decreasing value is higher when the temperature of drying medium is lower than when it is higher.
- Duration time for main stage of drying, is increasing, when you move from the lower to the upper value for the drying medium velocity, and the increasing value is approximately the same when temperature of drying medium is lower or when it is higher.
- Duration time for main stage of drying, is increasing, when you move from the lower to the upper value the drying medium velocity, and the increasing value is higher when the drying medium humidity is lower than when it is higher.

For sample B it can be concluded that:

- Duration time for main stage of drying, is decreasing when you move from the lower to the upper value for the drying medium humidity and the decreasing value is higher when the temperature of drying medium is lower than when it is higher.
- Duration time for main stage of drying, is increasing, when you move from the lower to the upper value for the drying medium velocity, and the increasing value is higher when the temperature of drying medium is lower than when it is higher.
- Duration time for main stage of drying, is increasing, when you move from the lower to the upper value the drying medium velocity, and the increasing value is higher when the drying medium humidity is lower than when it is higher.

4. CONCLUSION

It was established a mathematical dependence of duration time for main stage of drying for inactivated (t_{mainA}) and active sample (t_{mainb}) from the temperature, humidity and speed of the drying media. The analysis of temperature, humidity and velocity of drying medium on the duration time for main stage of drying value was done. The output values from model can serve as the basis for the optimization of drying masonry products process and the establishment of the fast drying regime of same products. The model I was tested in a local factory, and the result was good. Approximately the same value for the duration time for main stage of drying was obtain experimentally in the factory and by using a model I.

5. AKNOWLEDGEMENTS

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