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Investigation of Microwave Drying of a Firefighting Hose

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Highlights

• Drying the fire fighting hose within the shortest time.
• The drying method that can be practised in the fire fighting industry.
• Logarithmic model was selected as best curve fitting technique for drying rate.
• The temperature distributions in the samples were seen by an infrared camera.

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Abstract

The hoses used for fire extinguishing must be dried and stored after use in order to be cleaned, maintained and long-lasting. For this purpose, microwave energy which is a fast drying technology, was applied at power values of 2450 MHz and 120 W, 350 W and 460 W. The aim here is to dry the hoses quickly and show the effect of microwave energy by looking at SEM images and taking thermal photographs. In addition to it, nine drying models were compared with each other in order to determine the moisture content of the hose. The performances of these models were compared according to the correlation coefficient value (r), the estimated standard error (es) and the sum of squares of the residuals ($\chi 2$). According to the results, it was determined that the Logarithmic model for all drying conditions explains the drying behavior of the products better than the others. In addition, the effect of microwave drying did not cause a change on the internal structure of the sample but in consequence of thermal analysis, a fast rising was observed in the sample's temperature with the energy rise.

1. INTRODUCTION

In fire stations, hoses are used in many processes such as water extraction and delivery, especially for fires. Hoses are produced in different types according to the process they are used. In the firefighting process, the hoses play a role in extinguishing the fire by carrying the pressurized water coming from the fire trucks or hydrants to the fire place. In the production of hoses, attention is paid to the quality of the materials they are manufactured, to be resistant to at least three atmospheres more pressure than the average pump pressure of the vehicle used, to not harden and lose its protective softness when wet, as well as to be resistant to rot and mold [1, 2].

There are different types of hoses on the industry. "A type" hoses which are used in flooding or withdrawing water from anywhere are produced in 110 mm diameter and 1.6-3 m length. "B Type" hose produced with a diameter of 75 mm and a length of 25 m is used in fire interventions and also for water extraction. It is "C type" hose with a diameter of 42-52 mm and a length of 20 m and often used in firefighting operations. There is no structural difference with "B type" hoses except diameter and length values. "D type" hose with a diameter of 25-28 mm produced in different lengths between 40 and 60 m, and usually wrapped on fire trucks. They are being used with fast response lances [2,3].

In this study, especially B type hoses which are being used for firefighting purposes in fire stations were examined. These hoses are cleaned after each use with the help of soap and water. In this way, the hoses prepared for other uses should be dried before storing. In the current situation, the hoses are hanged with a reel system to the drying pole located outside the fire station in summer and inside the fire station in winter months, and the drying process is provided by environmental factors [4].

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Disadvantages of the system is being used today; especially in winter, drying time is quite long and the hoses cannot be dried at the same time, since a certain amount of hose can be hung on the drying pole at one time. The reason for using this system is that its cost is very low and drying by natural means does not cause any damage to the structure of the fire brigade hose. Cleaned hoses are dried in a natural environment. In order not to damage the structure of the hoses, they should not be dried under extreme sun and by contacting them with hot surfaces [3].

Today, hose dryers, which are being used, are seen as very costly and occupying a lot of space in fire stations. The machines used for laying-collecting and drying of fire fighting hoses in fire stations located in different regions were also examined in the study. These machines are generally designed to be quite large and their prices are expensive, as another factor that reduces their preference.

In current systems, since these hoses are quite long, they are dried naturally by hanging them up. In this work, the aim is to dry the hoses as fast as possible with microwave energy for emergencies. In recent literature, there is no other work found that involves drying hoses with microwave energy. The effects of this quick method, microwave drying, on the interior of the hose and drying characteristics are investigated.

2. FIRE FIGHTING HOSE AND DRYING SYSTEM

Firefighting hoses (as shown Figure 1) are used as standard in fire stations and consist of fabric on the outside and rubber on the inside. A special glue is used to bind the rubber and fabric parts together. Working between 10 - 40 bar can be done with rubber hoses. In this study, 20 m long firefighting hose sold in the market, 20 cm long samples were cut and used in the experiments [5]. Before the experiment, lances at the beginning and end of the hoses were removed and studies were carried out only on the hose part. The initial weights of the cut samples were measured with a precision balance (Presica XB 620 M, Precisa Instruments AG, Dietikon, Switzerland) with an accuracy of 0,001 g.

Figure 1. *Fire Fighting Hose*

Microwave drying oven (Arçelik MD554, Turkey) at 1200 W and 2450 MHz was used for the drying (as shown in Figure 2). The experiments were done at 120, 350 and 460 W microwave power levels. A precision scale is used for weight measurements at certain intervals.

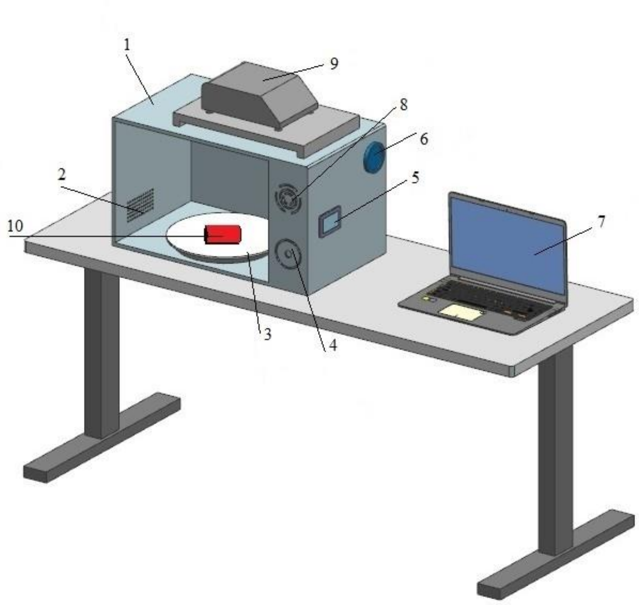


Figure 2. *Microwave Dryer (1: Drying Room, 2: Moisture Outlet, 3: Plate, 4: Timer, 5: Electromagnetic Wave Generator, 6: Cooler Fan; 7: Data Recorder, 8: Electrical energy (on/off), 9: Balance, Firehose)*

2.1. Drying Procedure

For this study, hose samples were exposed to water for 90 minutes, considering the conditions of use of the hoses. The samples that were used in the experiments were absorbed water in a deep bowl of 17 cm diameter and 28 cm height, and the samples were kept in the water bath for 90 minutes, and their wet weights were measured and recorded with the help of sensitive scales.

A hose sample prepared by pre-absorbing water was placed on the tray in the microwave dryer. Microwave drying processes are performed at 2450 Hz and 120 W, 350 W and 460 W power values. The measurement periods of the experiment vary according to the power value applied in the microwave dryer. Weight and thermal measurement (Flir EX E6, Estonia) was applied in 3 minutes when the 120 W value was applied to the samples, in 1 minute when the 350 W value was applied, and in 0.5 minutes when the 460 W value was applied. Temperature changes were analyzed with the thermal images and results obtained.

The hose sample used in the experiments was dried in the oven (MINGDA KIT-35A, China) at 105 ° C for 24 hours in order to determine the initial moisture value. Moisture changes are calculated taking into account the weight of the product. During the drying process, the measurements made in the microwave dryer at various times (0.5 min, 1 min and 3 min) and the weight changes of the hose samples were noted.

Theoretical and experimental models are being formed for different products. Being able to identify drying characteristics of samples depends on modeling the drying correctly. The moisture ratio was obtained from Equation (1) [6]

$$m_R = \frac{m - m_e}{m_o - m_e} \tag{1}$$

where m (g water/g dry mater.min) is the moisture content at a specific time, m_o (g water/g dry mater. min) is the initial moisture content, m_e (g water/g dry mater. min) is the equilibrium moisture content. The m_e value is very small value compared to m and m_o. m_e can be simplified by taking zero for microwave drying. The experimental moisture ratio versus drying time data were fitted in nine thin layer drying models in Table 1.

Table 1. *Mathematical Models and Equations*

Mathematical Model	Model Equation	Reference
Henderson & Pabis	m_R= α exp (-kt)	[7]
Newton	m_R= exp (-kt)	[8]
Wang & Singh	m_R= 1 + αt + bt^2	[9]
Logarithmic	m_R= α exp (-kt) + b	[10]
Midilli et al.	m_R= α exp (-kt^n) + bt	[11]
Copace	m_R= (α + bt) / (1 + ct + dt^2)	[12]
Approximation of Diffusion	m_R= α exp(-kt) + (1-α)exp(-kbt)	[13]
Verma et al.	m_R= α exp(-kt) + (1-α)exp(-gt)	[14]
Two Term Exponantial	m_R= α exp(-kt) + (1-α)exp(-kαt)	[15]

For the acceptability of any model, it is preferred that the correlation coefficient (r) is close to 1 and the standard deviation and chi-square (χ2) value is close to 0 in Equations (2)-(4) [16]

$$r = \frac{n_o \sum_{i=1}^{n_o} mr_{pre,i} mr_{exp,i} - \sum_{i=1}^{n_o} mr_{pre,i} \sum_{i=1}^{n_o} mr_{exp,i}}{\sqrt{n_o \sum_{i=1}^{n_o} (mr_{pre,i})^2 - \left(\sum_{i=1}^{n_o} mr_{pre,i}\right)^2} \sqrt{n_o \sum_{i=1}^{n_o} (mr_{exp,i})^2 - \left(\sum_{i=1}^{n_o} mr_{exp,i}\right)^2}}\,, \tag{2}$$

$$e_s = \sqrt{\frac{\sum_{i=1}^{n_o} (mr_{pre,i} - mr_{exp,i})^2}{n_o}}\,, \tag{3}$$

$$\chi^2 = \frac{\sum_{i=1}^{n_o} (mr_{pre,i} - mr_{exp,i})^2}{n_o - n_c}\,. \tag{4}$$

In these equations; mrexp, i: the dimensionless moisture ratio obtained as a result of the experiment, mrpre, i: the dimensionless moisture ratio obtained in the appropriate model, no: the number of observations, nc: the number of constants in the drying model and n: the exponent value.

In order to determine in detail the changes in the internal structure of the samples after drying, imaging was performed with the help of SEM (FEI Quanta-Feg 250, USA). In order to obtain images of the samples with the help of a SEM device, 1 cm2 sized pieces of dried samples were taken. The fragments taken from both the upper and lower surfaces of the sample with a knife were examined and photographed. With the images obtained from the device, the internal structure of the sample was enlarged 2000 times and the changes were compared with each other.

3. RESEARCH FINDINGS

Moisture change from the data obtained in microwave drying is given in Figure 3 for each parameter. Microwave drying was carried out for 10.5, 13 and 54 minutes at different powers at 90 minute water bath, respectively. The final moisture values varied between 0,0599-0,0635 g water / g dry matter.

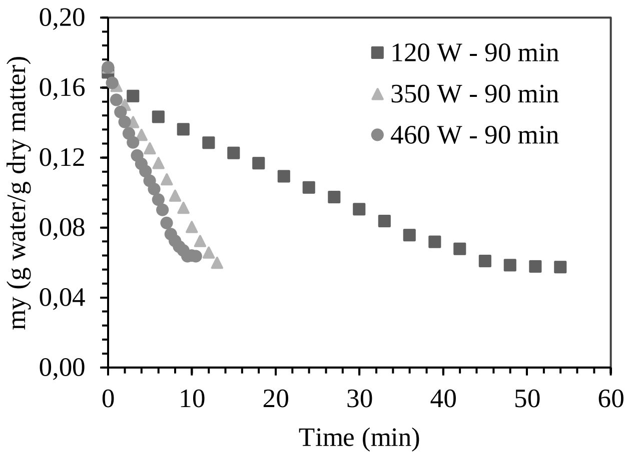


Figure 3. *Moisture change in different microwave powers of the hose, where 90 minutes of water bath is applied*

3.1. Mathematical Modeling

Mathematical modeling was also performed according to the data of the hose sample after the drying process in the microwave dryer. Thus, the compatibility between the experimental results and the models was examined. The results of the mathematical models are in Table 2. The logarithmic model is the most suitable mathematical model. The compatibility of the model with the experimental data is given in Figure 4.

For the mathematical modeling process, Approximation of Diffusion, Verma et al., Midilli et al., Wang & Singh, Henderson & Pabis, Newton, Copace, Two Term Exponantial and Logarithmic models were used [17]. Newton, Wang & Singh, Copace, Logarithmic, Henderson & Pabis, and Verma et al for specimens kept in a water bath for 90 minutes and dried in a microwave dryer was observed to be suitable for samples dried. When all results were evaluated, it was determined that the most suitable model was Logarithmic. Many studies have been carried out with Logarithmic model on drying [18], [19], [20].

Table 2. *90 minute water bath experiments - mathematical modeling results*

MODEL	Microwave Power (W)	Constants	r	χ^2	e_s
NEWTON	120	k= 0,0214	0,993	0,00024	0,0155
	350	k= 0,075	0,993	0,00022	0,0151
	460	k= 0,101	0,993	0,00023	0,0152
COPACE	120	a= 0,946; b= -0,0013 c= 0,0126; d= 0,00037	0,996	0,00018	0,0133
	350	a= 0,957; b= 0,06 c=0,092; d= 0,014	0,995	0,0002	0,0144
	460	a= 0,966; b= 0,002 c= 0,068; d= 0,0106	0,995	0,00022	0,015
HENDERSON & PABIS	120	a= 0,98; k= 0,021	0,995	0,0002	0,0142
	350	a= 1,006; k= 0,076	0,993	0,0002	0,015
	460	a=1,001; k= 0,101	0,993	0,0002	0,016
WANG & SINGH	120	a= -0,02; b= 0,00014	0,993	0,00027	0,016
	350	a= -0,07; b= 0,002	0,995	0,0002	0,013
	460	a= -0,094; b= 0,003	0,994	0,0002	0,014
LOGARITHMIC	120	a= 0,96; k= -0,018; b= 0,0001	0,996	0,0002	0,013
	350	a= 1,003; k= -0,073	0,995	0,0002	0,014

		b= 0,0019			
	460	a= 0,988; k=-0,09 b= 0,003	0,995	0,0002	0,014
APPROXIMATION OF DIFFUSION	120	a= 11,864 ; k= 0,00099 b= 11,956	0,980	0,0009	0,03
	350	a= -54,747; k= -0,00081 b= -54,683	0,974	0,0012	0,0356
	460	a= -27,799; k= -0,0021 b= -27,729	0,979	0,00092	0,0303
VERMA ET AL.	120	a= 0,292; k= 0,012 g= 0,026	0,993	0,0003	0,0165
	350	a= -0,043; k= 0,016 g= 0,072	0,993	0,0003	0,0160
	460	a= -0,0077; k= 0,055 g= 0,098	0,992	0,0003	0,0181
TWO-TERM EXPONENTIAL	120	a= 11,864; k= 0,00099	0,980	0,0009	0,0301
	350	a= 54,747; k= -0,0008	0,974	0,0012	0,036
	460	a= -27,79; k= -0,0021	0,979	0,0009	0,030
MIDILLI ET AL.	120	a= 0,906; k= 0,0007 n= 0; b= -0,01	0,981	0,0008	0,029
	350	a= 0,939; k= 0,0034 n= 0; b= -0,04	0,979	0,00089	0,029
	460	a= 0,93; k= -0,0053 n= 0; b= -0,061	0,983	0,00013	0,0115

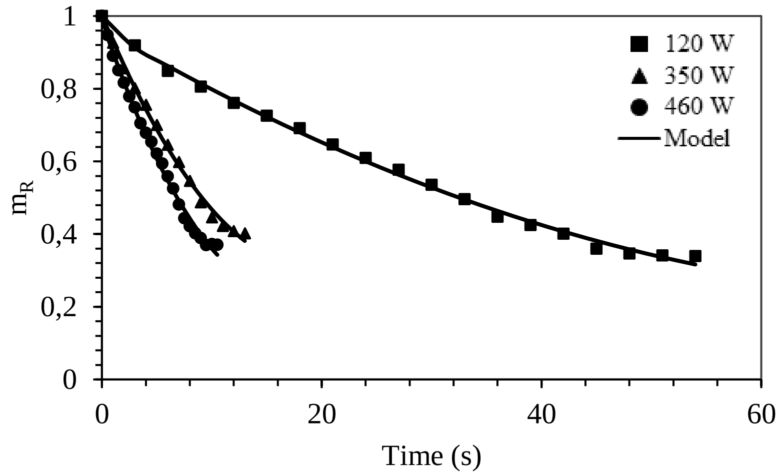


Figure 4*. Logarithmic Model fit chart*

3.2. Thermal Analysis

During the drying process performed in the microwave dryer, thermal analysis was performed on the hose samples. In the samples imaged with the help of a thermal camera, it was observed that the areas with more moisture were at higher temperatures. The parts observed as yellow in thermal analysis are the parts that continue to heat while the red parts are overheated by energy absorption. This is due to the absorption of larger amounts of microwave energy in areas with high moisture. However, excessive temperature increase can also cause partial burns depending on the drying time.

In the drying process performed in the microwave dryer, it was determined that the sample temperature increased faster as the power increased and regional temperature differences occurred according to the absorption of microwave rays. It was also stated in the study of Huang et al. [21] that this situation, which occurred in microwave drying, was caused by irregularities in the electromagnetic field.

Figure 5 shows the thermal camera images of the hose sample during drying in a microwave dryer by applying 120 W power. Drying process lasted 54 minutes and the first temperature of the hose sample measured at the 3rd minute was 37.4° C, while the final temperature measured at the 54th minute was 63.1° C. The temperature increases during the drying process. However, the temperature distribution is uneven and high temperatures were observed in the corners of the samples with high density [2, 22, 23].

Figure 6 shows the thermal camera images of the hose sample during drying in a microwave dryer by applying 350 W power. The drying process continued for 13 minutes. The measured first temperature of the hose sample was 66.6° C in the first minute, and the final temperature was measured as 125° C in the 13th minute. During the process, the sample temperature tends to increase continuously. The temperature distribution shows an uneven distribution throughout the process. Generally, high temperatures are distributed on the surface in the middle of the drying process, but completely uneven temperature distribution has been detected in the last measurements [2, 22, 23].

Figure 7 shows the thermal camera images of the hose sample during drying in a microwave dryer by applying 460 W power. Drying process lasted 10.5 minutes and during this process, the first temperature of the hose sample measured in 0.5 minutes was 38.7° C, while the final temperature measured at 10.5 minutes was 73.1° C. The sample temperature increased during the process. The temperature is distributed in the right and left parts throughout the process. Generally, high temperatures are seen on the surface in the middle of the drying process, but in the last measurements, high temperature values were detected on the right and left edges [2, 22, 23].

High energy absorption and high drying rates lead to overheating in certain regions during drying. Overheating results in regional burns and makes it difficult to control. In Figures 6 and 7, these regional burns can be seen in the final product. As the microwave power increased, the temperature of the final product increased [23, 24].

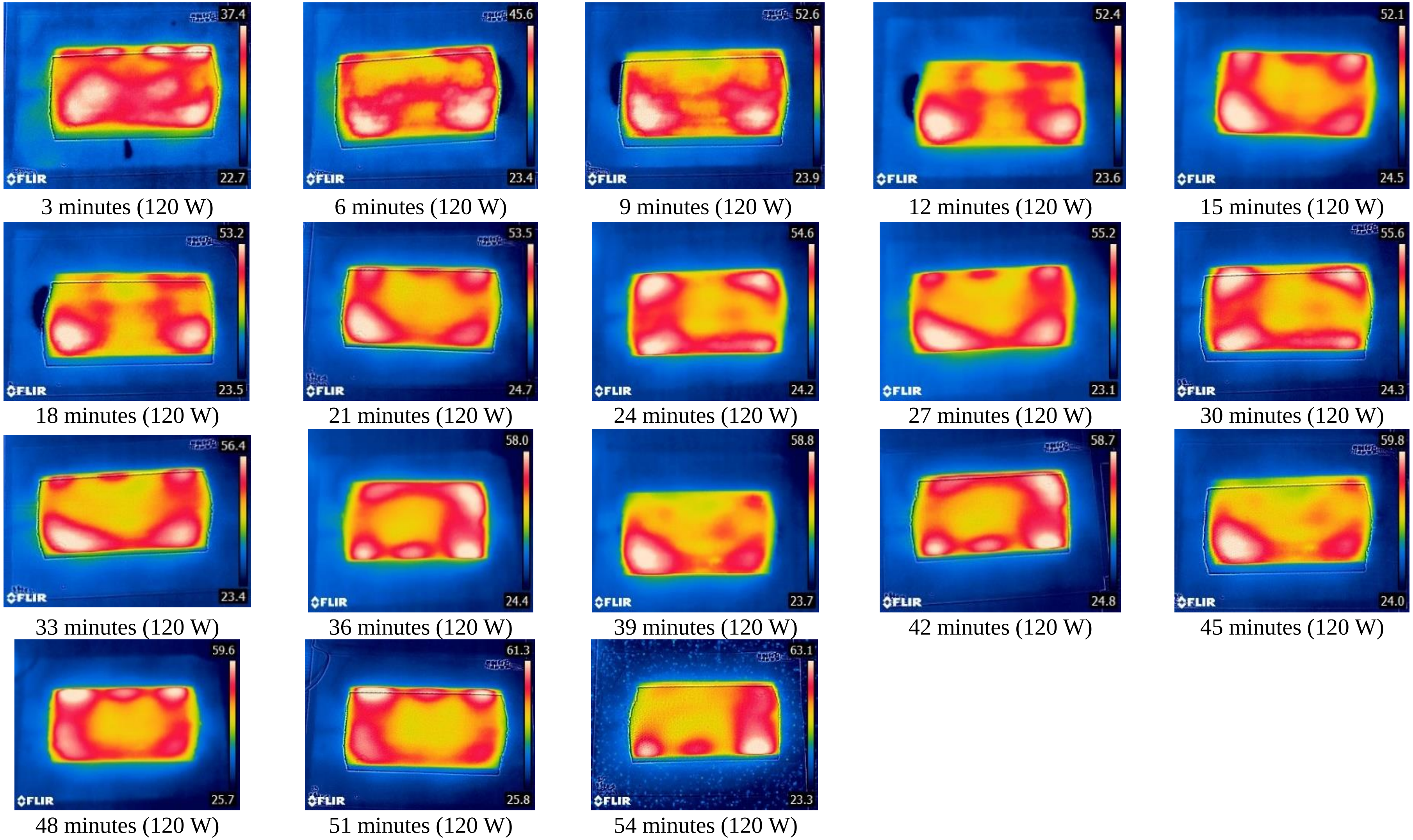


Figure 5. *Microwave drying at 120 W - 90 minutes water bath*

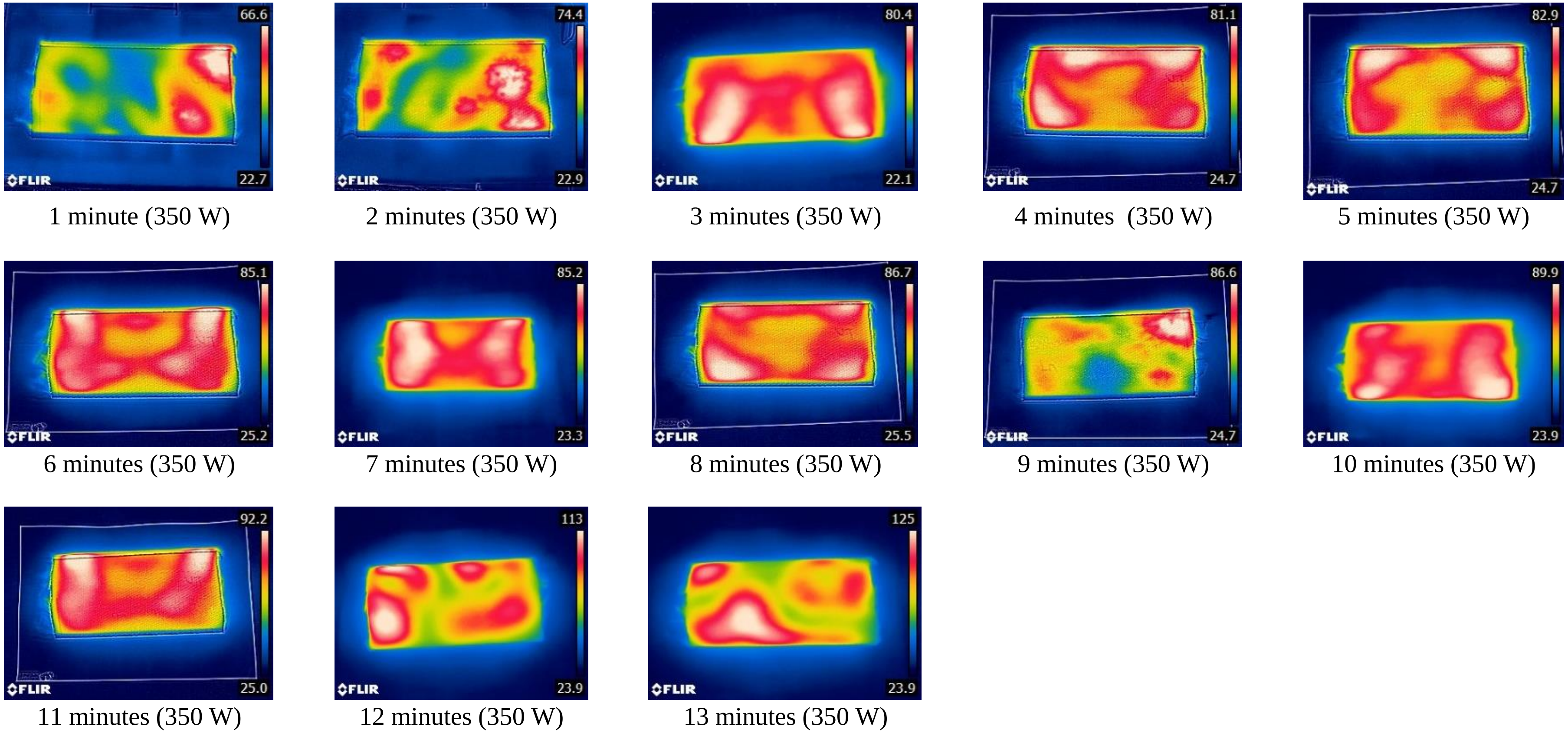


Figure 6*. Microwave drying at 350 W - 90 minutes water bath*

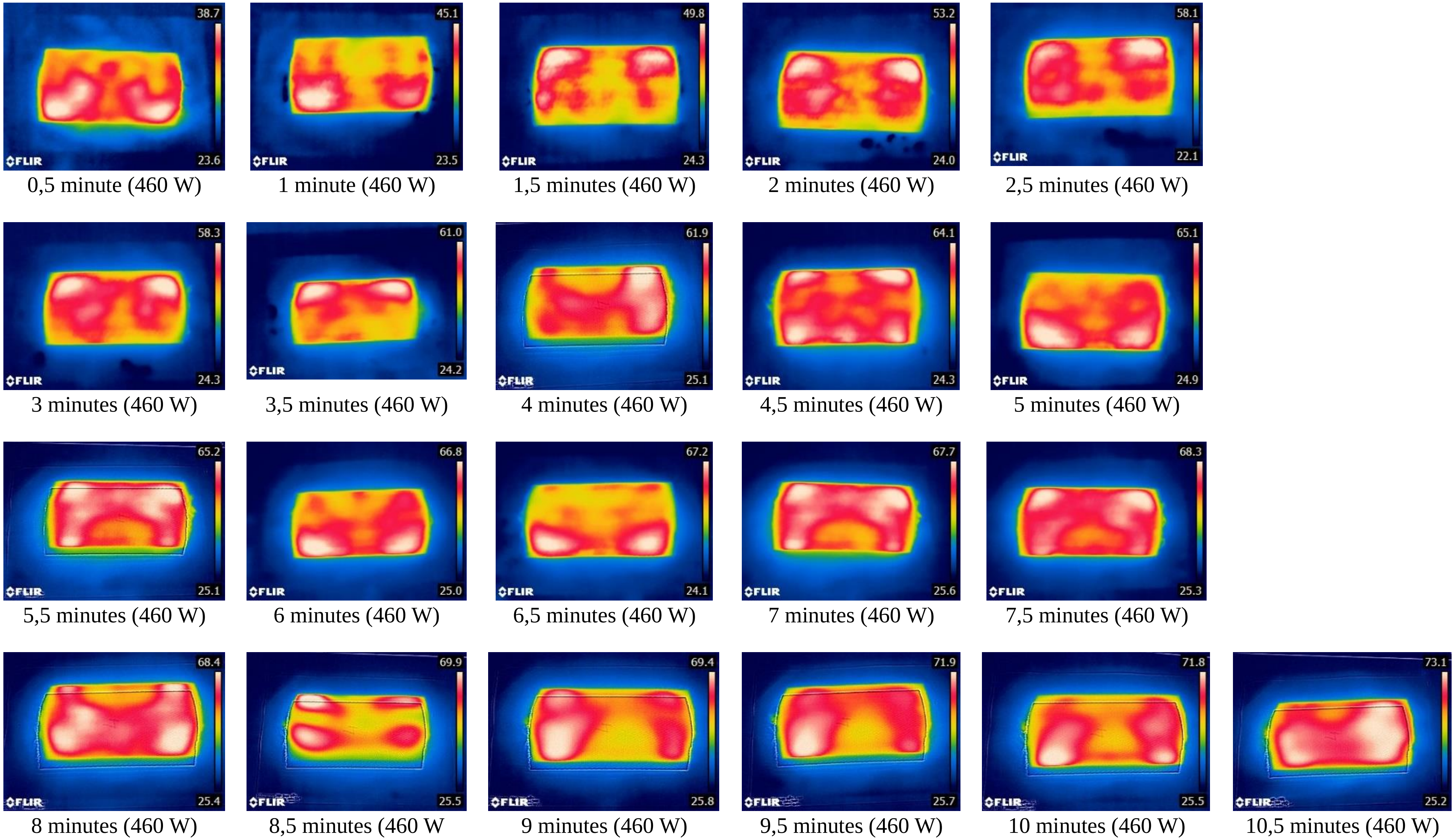
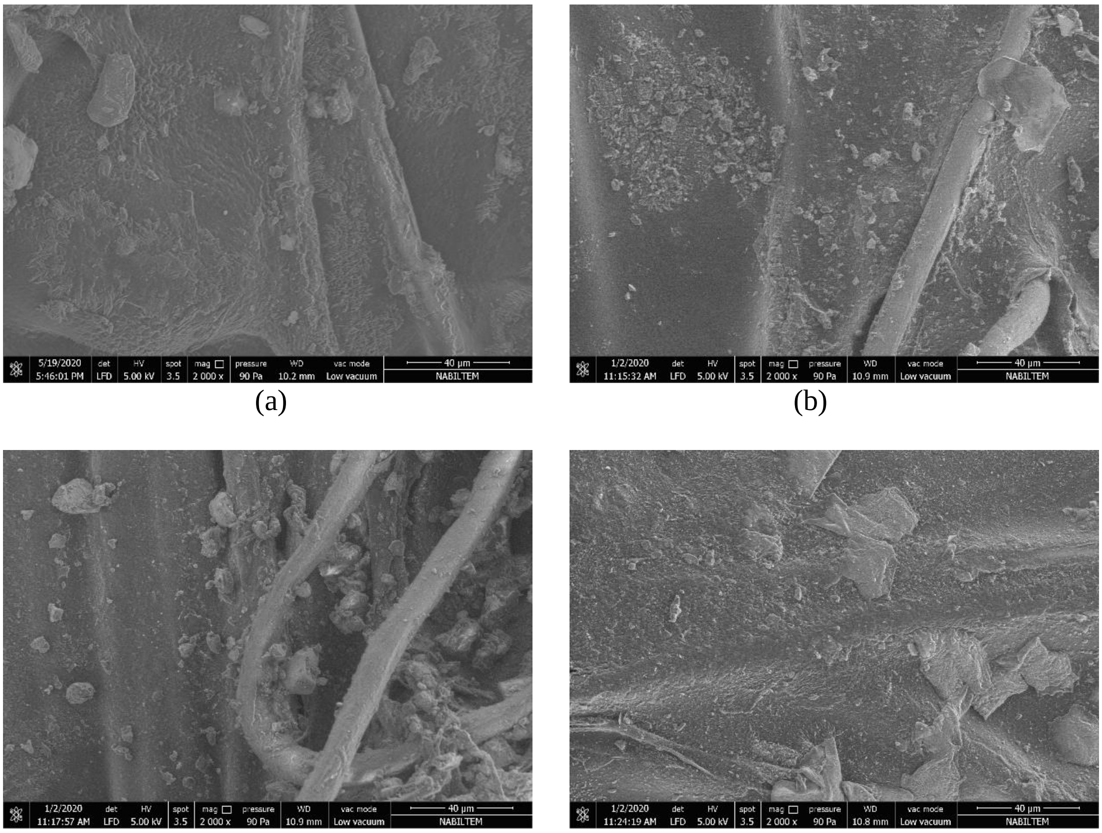


Figure 7. *Microwave drying at 460 W - 90 minutes water bath*

3.3. SEM Analysis

In order to understand whether there were physical changes in the inner structures of the tubing samples, the samples dried in a microwave dryer were imaged with the help of Scanning Electron Microscope (SEM). From the inner and outer parts of the hose sample, 2 mm long and 1 mm wide parts were used and the images of the microstructure of the sample were obtained by enlarging 2000x. Images of the untreated hose sample and the dried hose sample were compared. SEM (scanning electron microscope) images showing the inner structure of the outer part of the hose sample before and after drying are shown in Figure 8. In Figure 9, there are images of the inner part of the same hose sample.

It was observed that the number of pores increased with the drying power [2]. As the power level increased since the structure before drying, the number of pores increased and pores were enlarged. Increasing power levels increases the temperature and vapor pressure inside the structure. Large pores were formed due to the steam release. As can be seen in Figures 8-9, the material has lost its homogeneity. In the drying process in the microwave dryer, it was observed that as the power increased, the filament structure of the sample on the outer part and the porous structure on the inner part of the sample increased partially. Çelen [24] in his study on the drying of persimmon, found that the microwave power and the porous structure changed in direct proportion.



(a) (b)

(c) (d)

Figure 8. *SEM images of the exterior before and after drying, a) wet, b) 120 W, c) 350 W and d) 460 W*

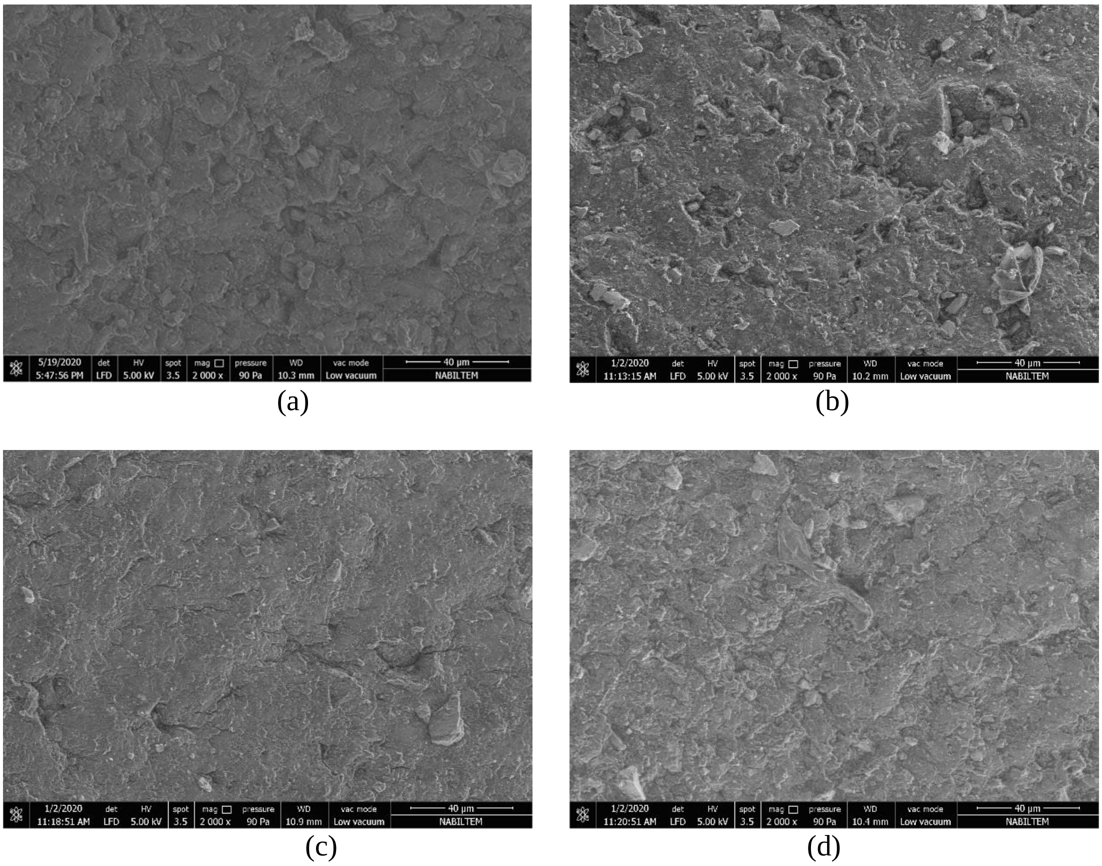


Figure 9. *SEM images of the interior before and after drying, a) wet, b) 120 W, c) 350 W and c) 460 W*

4. CONCLUSIONS

In consequence of drying the fire fighting hose which was kept in the water for 90 minutes, with the microwave, the conclusions regarding the experiments which were carried are as follows;

- The length of the drying process decreased as the power that was applied to the microwave dryer increased. The shortest drying process was seen in the 350 W microwave power.
- When the internal structures of the samples dried in a microwave dryer is compared with the sample that was not processed at all, no change was found to cause a negative impact on microwave drying.
- It was determined that the sample temperature increased faster as the power increased and regional temperature differences occurred according to the absorption of microwave rays. At the areas with more moisture there was higher temperatures.
- At the end of the experiments, the temperature of the product was measured at 37,4 ^{o}C minimum and as 125 ^{o}C at maximum. Thermal analyses have shown that the effect of power level on the product are important.
- The Logarithmic model’s suitability was proven for drying the fire fighting hose that was kept in the water for 90 minutes.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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