Investigation on Relationship between Shape Memory Effect and Interconnection Porosity under Multiple Sintering Time of Smart Alloy Cu-Al-Ni

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Abstract:-

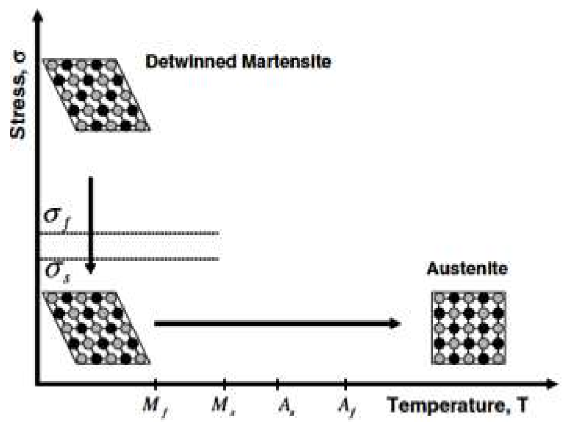
For Producing shape memory alloy In this study the powder metallurgy method has been used to manufacture Cu-13%Al-4%Ni alloy by producing 5 samples every sample sintered in difference sintering time(3,4,5,6,7) hours. The samples also heat treated to stabilize Martensite phase. The result of shape recovery and porosity testing analyses by using artificial neural network predicting system to predict shape recovery and porosity behavior between three and seven sintering hours with smaller time step Due to there is no physical relationship between porosity and shape recovery,. The relationship between porosity and shape effect curved by using excel program taking the result from predicting system of artificial neural network. The curves shows direct relationship between shape recovery and porosity with respect to time.

Key Words: Powder metallurgy, Shape effect, Porosity, Neural network.

1. Introduction

A smart material is a term used to describe material that have an ability to adjust its properties and shape due to change in applied stress and or temperature. There is more than one application make smart materials or smart alloy very importance like

Actuators or piping fastener's or medical applications **[1].** Cu-Al-Ni alloy get attention as smart alloy because its ability to work fine at high temperature about 200°C **[2].** The parent phase of Cu-Al-Ni smart alloy is austenite phase; to change it to Martensite must shear lattice distortion happen by quenching or super cooling. To return it to austenite phase a heating action must be done **[3]. Fig. 1** shows this fact and **Table 1.** shows the heat



transformation temperature for multiple smart memory alloys

Fig. 1 phase transformation [3]

Table 1. Heat transformation temperature for multiple alloys[4]

Alloy	Composition	Transformation-temperature range °C	Transformation-temperature range °F
Ag-Cd	44/49 at.% Cd	−190 to −50	−310 to −60
Au-Cd	46.5/50 at.% Cd	30 to 100	85 to 212
Cu-Al-Ni	14/14.5 wt% Al 3/4.5 wt% Ni	−140 to 100	−220 to 212
Cu-Sn	≈15 at.% Sn	−120 to 30	−185 to 85
Cu-Zn	38.5/41.5 wt% Zn	−180 to −10	−290 to 15
Cu-Zn-X (X = Si, Sn, Al)	a few wt% of X	−180 to 200	−290 to 390
In-Ti	18/23 at.% Ti	60 to 100	140 to 212
Ni-Al	36/38 at.% Al	−180 to 100	−290 to 212
Ni-Ti	49/51 at.% Ni	−50 to 110	−60 to 230
Fe-Pt	≈25 at.% Pt	≈−130	≈−200
Mn-Cu	5/35 at.% Cu	−250 to 180	−420 to 355
Fe-Mn-Si	32 wt% Mn, 6 wt% Si	−200 to 150	−330 to 300

The most important application of smart alloys is actuator recovery. **Fig. 2** shows temperature actuator switch. If the switch is designed to close above the Af temperature (top), a straight rod of alloy in initial shape is cooled to martensite phase (red color). Then an alloy is reshaped under stress. When the rod is heated above Af temperature, the martensite disappears and the rod straightens, closing the switch. If the switch is designed to open above Af temperature, the rod must be bent before cooling (bottom). The rod is then straightened out before it is placed in the switch

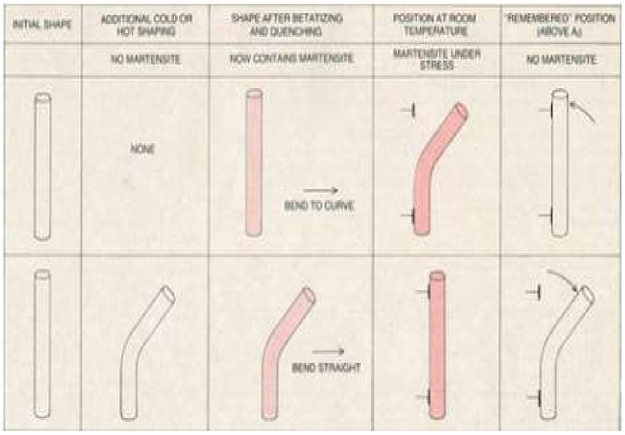
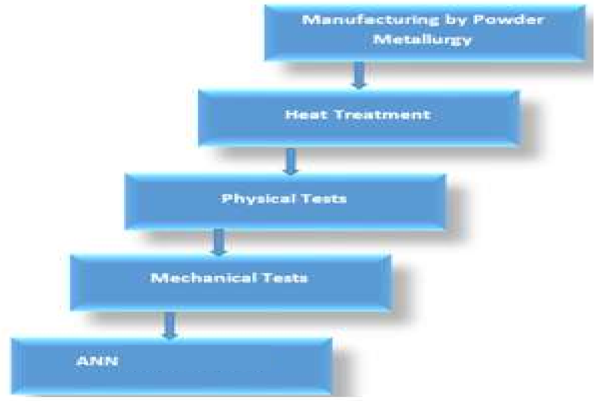


Fig. 2 Temperature–actuated switch. [5]

2. Artificial neural network(ANN)

Artificial neural network is an algorithm that use artificial intelligent to realize data and understand how it works. Like human nerve system artificial neural network can predict result by depending on neurons and the connection between them (weights). Input signal coming from input layer through connections or weights to the neurons and finally to output layer to give the prediction data. The main principle of artificial neural network is training the network depending on previous input and output data **[6].** In this paper artificial neural network is used to predict the behavior of Cu-Al-Ni alloy between multiple sintering times. The flowchart below shows the work of this paper



3. Experimental work

i) The powder bought from (SKYSPRING NANOMATERIALS USA) with purity of 99% and mesh (-325). The powder tested by using optical microscope before mixing to see the particle configuration. It is then mixed by using horizontal drum machine. The percentage of mixing powder was Cu-13%Al-4%Ni. The powder was tested by optical microscope to see the way of interlock between particles.

ii) The powder then compacted under 650 MPA from both sides to increase the homogeneity along the sample. In this paper we produce five samples, every sample has two pieces. First piece cylindrical (11 mm dia. * 16.5 mm long) while the other is a disc piece (11 mm dia. * 5 mm long) for testing consideration where cylindrical for shape effect testing and the disc one for other tests.

iii) The samples were then sintered in vacuumed tube furnace in two stages. First stage every sample(disc and cylindrical) was sintered at 500 ℃ for 1 hour to avoid liquid sintering of aluminum due to low melting temperature of AL. the second stage was followed directly after first one, the second stage summed with sintering every sample at single sintering hour (3,4,5,6,7). The samples then left to cool in furnace.

iv) The next step was the heat treatment in order to stabilize the Martensite phase. The heat treatment summed up in two steps, quenching in iced water after one hr aging at 800 ℃ and then aging for two hrs. at 100 ℃.

v) Physical testing like X-RAY diffraction (XRD) and scanning electron microscopy (SEM) were conducted to make sure that we get the Martensite phase.

vi) The mechanical tests were shape recovery test and porosity test. The shape recovery test was done by compressing the cylindrical samples (L1) until 4% from its original shape reached (Lo) and then heat the sample to 250 C , hold the temperature at 250 C for 5 minutes and then leave to cool in room temperature until it is regain percentage of its original shape (L2).

The shape recovery can obtained by using equation 1**[7].**

$$\textbf{Shape Effect \%} = \frac{L2-L1}{L0-L1} * 100 \ldots\ldots\ldots 1$$

Depending on **ASTB B328** the porosity test was conducted, so the method summed by using the oil impregnate water weighting method by using the formula (2)**[8]**.

$$P = \left[\frac{B-A}{(B-C+E)*Do} * 100\right] * Dw \ldots\ldots\ldots\ldots 2$$

P= porosity

B=Mass of oil-impregnated specimen , gm,

A=Mass of oil-free specimen, gm,

E= Mass of wire in water (which handling the sample)

Do=Density of the oil,-0.88 gm/ cm^3

Dw= Density of water-0.997gm/cm^3

Fig. 3 shows all devices that used in manufacturing method (a) is the rotating drum,(b) is the mold and the universal machine jaws and (c) is the furnace with vacuum system

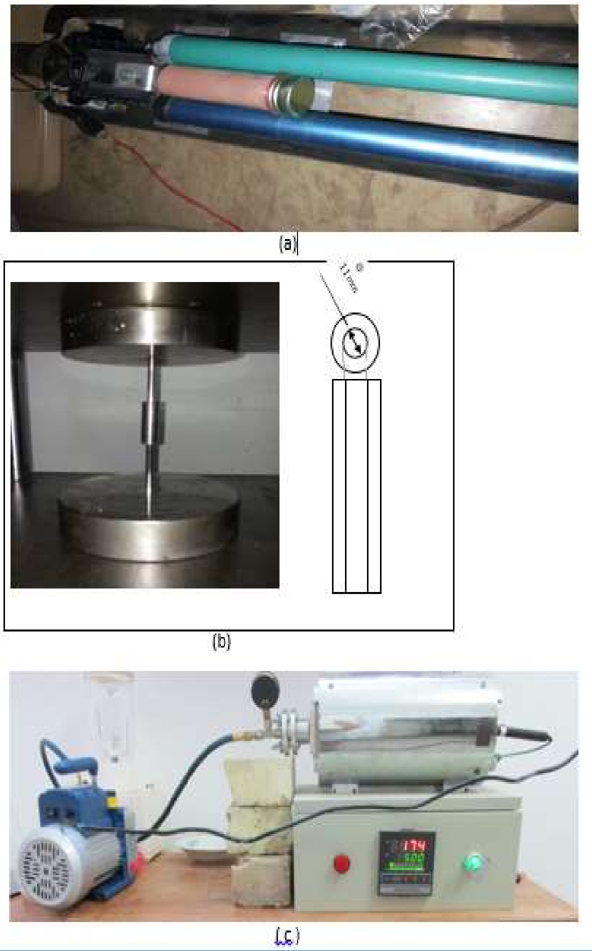


Fig. 3 the manufacturing devices

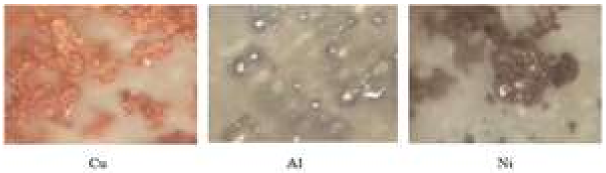
4. Results and discussion

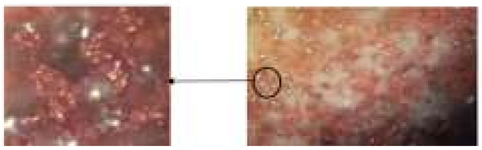
4.1 Physical testing results

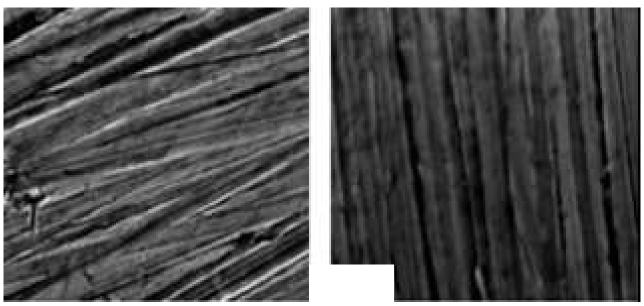
Fig. 4 shown the powder testing result under optical microscope before and after mixing ,where the Cu and Ni particles are annular but Al particles are globular to make the interconnection between particles easier after mixing . **Fig. 5** demonstrate the basic elements and distribution of elements after compacting, . The physical testing expand to investigate about the existence of Martensite phase. **Fig. 6-a** shown the needle Martensite phase of sample that sintered until 3 hours and **Fig. 6-b** shows the needle Martensite phase of sample that sintered until 7 hrs. but it is seems more clear compared with first sample. The previous testing conducted by using SEM device. XRD testing also used to see the peak of Martensite phase (AlCu3) as shown in **Fig. 7-a** for 3 hours sintered sample and **Fig. 7-b** for 7 hours sintered sample.

Fig. 4: the basic elements before and after mixing by using optical microscope 200X

Fig. 5 optical microscopy with 200X after compacting at 650 Mpa

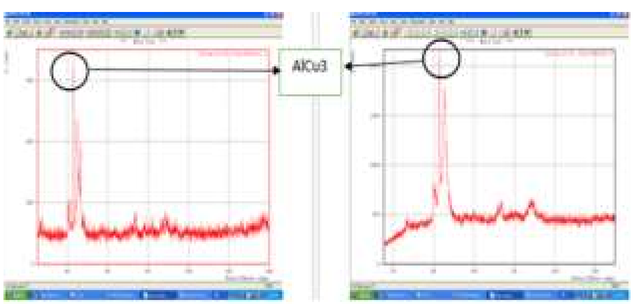






a b

Fig.6 SEM images of fully manufactured Cu-13%Al=4%Ni for two samples (a) sintered at 3 hrs. (b) sintered at 7hrs.



a b

Fig. 7 Martensite peak of fully manufactured Cu-13%Al=4%Ni for two samples (a) sintered at 3 hrs. (b) sintered at 7hrs.

4.2 Mechanical testing results

Table 2. shown the testing result of porosity and shape effect affected by time. The result plotted as a curve in **Fig. 8** and **Fig. 9.** The relationship between porosity and shape recovery in one variable was plotted as a curve in **Fig. 10.** Neural network is used for plotting previous curves as smoother and more accurate, because the ability of neural network to predict more data between three and seven sintering hours. In this paper we have one input variable (sintering time) five stages (3, 4, 5, 6, and 7) with output target (porosity and shape effect). Forward back-propagation algorithm and tan sigmoid transfer function have been used to train two networks the first one was for porosity the second one was for shape effect. The better number of neurons was 4 in first hidden layer and 1 neuron in second hidden layer for both networks. **Fig. 11** shows the general configuration of our network and **Table 3**. shows the weight values of both networks. It is then the prediction ability has been used to predict the values of shape effect and porosity every 5 minutes. **Table 4**. shows the predicting values so we repeat plotting **Fig.s (8, 9, and 10)** under mention of **Fig.s (12, 13, and 14)** depending on ANN results. The different is clear between them so that the curves of every 5 minutes outputs

are smoother than original curves. Note that we use MATLAB program and its neural network package in this paper

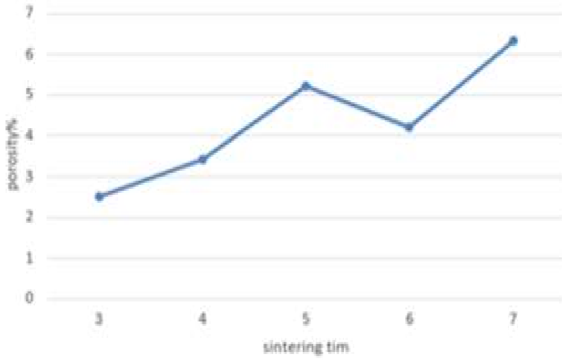


Fig. 8 : porosity with sintering time

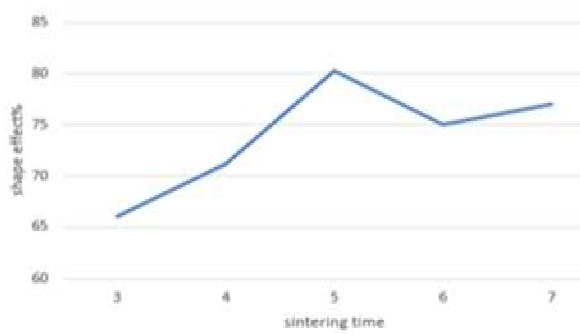


Fig. 9 shape effect with sintering time

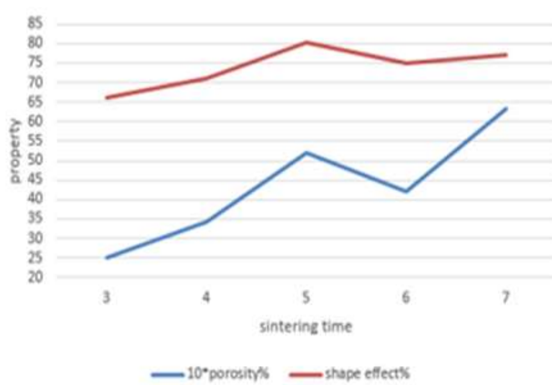


Fig. 10 Relationship between porosity and shape recovery with respect to time

Table 2. Testing result of porosity and shape recovery (shape effect)

Table 3. The weight values of porosity and shape effect networks

Sintering time hrs.	Porosity%	Shape effect%
3	2.5	66
4	3.43	71.2
5	5.21	80.34
6	4.2	75
7	6.34	77

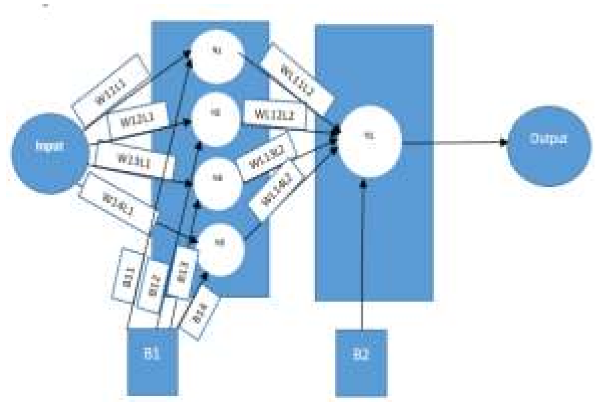


Fig. 11 Forward back propagation network used for training porosity and shape effect

Table 4. Neural network predicting values

Weights and bias	Shape effect	Porosity
W11L1	5.6097	6.5975
W12L1	5.5882	6.5105
W13L1	-5.6044	-5.0778
W14L1	5.6398	5.2107
B11	-5.59	-4.8153
B12	-1.8995	0.5112
B13	-1.8636	-2.5618
B14	5.5601	5.9904
WL11L2	0.54241	4.0685
WL12L2	-0.85595	-1.8483
WL13L2	-1.1422	-3.8453
WL14L2	0.32098	1.6212
B2L2	-0.10695	-0.040422

Sintering time hrs.	porosity	Shape recovery
180	2.500175	0.66
185	2.500261	0.68179
190	2.500364	0.68457
195	2.500488	0.687167
200	2.500656	0.689392
205	2.500924	0.691218
210	2.501429	0.692747
215	2.50256	0.69417
220	2.505593	0.695733
225	2.515525	0.697758
230	2.555047	0.700683
235	2.732436	0.705138
240	3.429999	0.712

Table 4. Continued

245	4.831097	0.722285
250	5.817448	0.736558
255	6.158304	0.75372
260	6.260163	0.770519
265	6.292916	0.783665
270	6.302409	0.792256
275	6.299289	0.797318
280	6.280322	0.800188
285	6.225429	0.801807
290	6.079579	0.802714
295	5.750303	0.803197
300	5.217805	0.8034
305	4.648596	0.803379
310	4.213282	0.803134
315	3.937444	0.8026
320	3.776749	0.801639
325	3.687732	0.799993
330	3.642953	0.797246
335	3.628219	0.792824
340	3.638954	0.786198
345	3.678966	0.777399
350	3.762168	0.767433
355	3.91799	0.75789
360	4.199999	0.75

365	4.681609	0.744181
370	5.36369	0.740271
375	5.983892	0.737913
380	6.267236	0.736792
385	6.330575	0.736729
390	6.338977	0.737698
395	6.339871	0.739814
400	6.339976	0.743284
405	6.339993	0.748297
410	6.339997	0.754817
415	6.339998	0.76236
420	6.339999	0.77

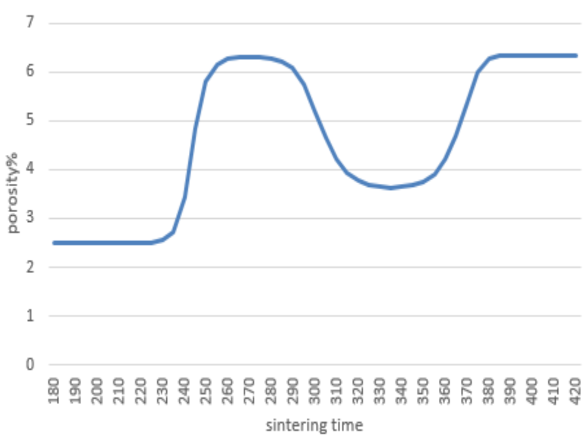


Fig. 12 Smooth curve between porosity and sintering time

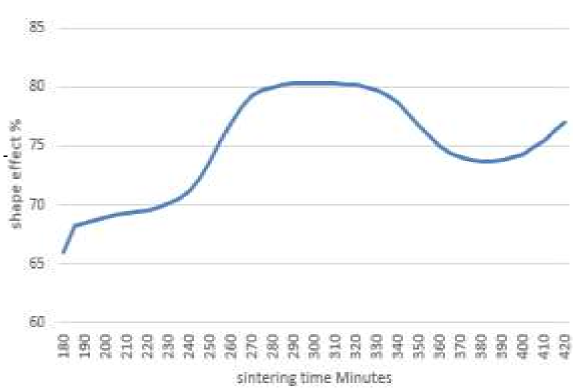


Fig. 13 smooth curve between shape effect and sintering time

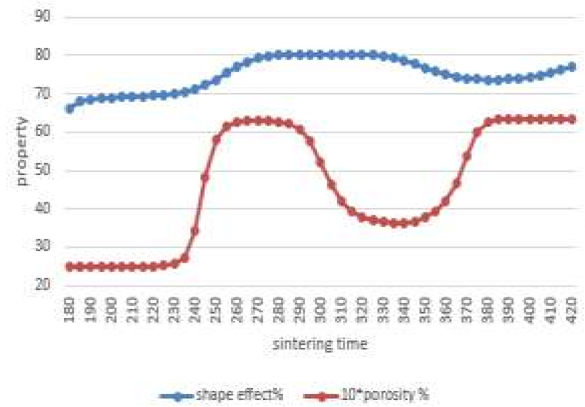


Fig. 14 More reliable relationship between shape effect and porosity with respect to time

From **Fig. 12** the relation between porosity and sintering time begin to be constant until approximately 235 minutes the relation become direct. The relation is indirect from minutes 260 to minutes 330. The relation return to be direct after that. From **Fig. 13** the relation between shape effect and sintering time is direct from minutes 180 to 280. It is then Indirect relation until approximately minutes 380 and then return to be direct. **Fig. 14** shows the relationship between shape effect and porosity. The relation is direct generally.

5. Conclusion

1- The Martensite details is more clear in 7 hrs sintering due to" the more sintering time, the more diffusion opportunity between atoms"
2- We can conclude the relation between shape effect and sintering time is cyclic tend to be direct. Also the relation between porosity and sintering time is direct cyclic .
3- We can conclude " the more porosity , the more shape effect. The direct relation between shape effect and porosity is due to void may help and make the compression easier.
4- Neural network make the relationship between porosity and shape effect smoother and more clear and help us to conclude the real relation between shape effect and porosity with respect to time
5- The suggestion for further works is to find the equation or formula between porosity and shape effect through studying the effect of (compacting pressure , sintering time, sintering temp., mixing speed and time, and aging time and quenching medium) together on relation between porosity and shape recovery

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بحث العلاقة بين الرجوعية والمسامية المتصلة عند تغيير زمن التلبيد لسبيكة ذكية (نحاس, المنيوم ,نيكل)

ألاستاذ المساعد الدكتور احمد عبد الرسول

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كلية الهندسة

قسم الهندسة الميكانيكية

الخلاصة :-

لتصنيع سبيكة ذكية في هذه الدراسة استدخدمت طريقة المساحيق في تصنيع سبيكة نحاس-13%المنيوم-4%نيكل وذلك بانتاج 5 عينات. كل عينة تم تلبيدها بوقت مختلف (3و4و5و6و7) ساعات. العينات تمت معالجتها حراريا بعد ذلك من اجل تثبيت طور المارتنسايت. تمت تحليل النتائج باستخدام طريقة الشبكات العصبية للتنبؤ بتصرف الرجوعية والمسامية بين ساعات التلبيد ثلاثة الى سبع ساعات مع خطوات زمنية اقل وذلك لعدم وجود علاقة فيزيائية تربط المسامية بالرجوعية . بواسطة استخدام برنامج الاكسل وبالاستفادة من نتائج التنبؤ للشبكات العصبية تمت عملية رسم منحنيات بين المسامية والرجوعية. المنحنيات بينت علاقة طردية بين الرجوعية والمسامية بالنسبة للزمن