# Artificial Neural Network Model for Predicting Compressive Strength of High Strength Concrete after Burning

Asst. professor Saif Salah Alquzweeni
Babylon University, College of Engineering, Department Of Civil Engineering
eng.saif.salah@uobabylon.edu.iq or saifalquzweeni@gmail.com

***Abstract*--** **In this investigation, the effects of elevated temperatures of 300, 550, 750°C for 1.0 hour at different ages of 28 , 56 and 90 days on the main mechanical properties of high strength concrete are studied. After burning, the concrete specimens were quenched in a water tank to provide the maximum shock due to sudden cooling. This study presents the effort in applying neural network-based system identification techniques to predict the mechanical properties of high strength. Back-propagation neural networks model is successively developed, trained, and tested using actual data sets from experimental.**

**The parametric study shows that temperature is the most significant factor affecting the output of the model. The results showed that artificial neural networks (ANN) has strong potential as a feasible tool for predicting compressive strength of concrete after exposure to fire flame.**

***Index Term*--** **Artificial neural network, Burning, High strength of concrete and Predicting.**

## INTRODUCTION

The micro-structural changes of concrete under high temperature involve complex physicochemical transformations in the material. The extent of the property variation depends on many internal and external parameters, such as concrete mix design, properties of the constituents, heating rate, temperature level etc(Willam et al, 2005 ).

Artificial neural network (ANN) does not need such a specific equation form. Instead of that, it needs sufficient input-output data. Also, it can continuously retrain the new data, so that it can conveniently adapted to new data. Modeling with ANN is much simpler because, although a neural network captures the mathematical relationships in its collection of interconnections between its nodes, no formal mathematical rule or formulae are used or observed within the model.

Over the last two decades, different predicting methods based on ANNs has become popular and has been used by many researchers for a variety of engineering applications (Sanad and Saka, 2001), (Jung and Ghaboussi, 2006) and (Salim, 2007).

Several investigations have shown that the deterioration in the compressive strength of concrete under high temperature exposure. There are indeed rare researches about temperature gradient and exposure time of the concrete indirect contact with the fire flames. In this study there is an attempt to investigate the effect of temperature gradient and exposure of high strength concrete to fire flames on compressive strength, tensile strength and flexural strength of high strength concrete .

High strength concrete, in comparison with medium strength concrete, is more brittle; contains less water; and the solid particles are more compact. Hence, the effects of high temperature on high strength concrete will be different to those with the medium strength concrete. ( Sri Ravindarajah ,1998) studied the effect of temperature up to 800°C and method of cooling on the compressive and tensile strength of high-strength concrete .

### Major problems of concrete when exposed to fire

Fire incurs two major problems on concrete. The first is the deterioration in mechanical properties of concrete, such as physicochemical changes of the cement paste and aggregate, thermal incompatibility between the aggregate and the cement paste according to temperature level, heating rate, applied load, and external sealing which prevents moisture loss from the surface of concrete.

The second problem is spalling of concrete. Spalling means the break off of layers or pieces of concrete from the surface of a structural element. The spalling of normal concrete occurs due to rapid temperature increase- typically 20$^{o}$C/min (Khoury, 2000). High strength concrete (HSC) has a significantly higher potential for explosive spalling than normal strength concrete (NSC ) due to its low permeability. Explosive spalling of HSC may occur even at relatively low heating rate - less than 5$^{o}$C/min (Phan and Carino, 2002).

Spalling can lead to severe reduction of the of the cross sectional area, which in turn, leads to the exposure of the reinforcing steel to excessive temperatures (Willam et al, 2005).

Selection of the concrete mix design is very important in the fire design for reinforced concrete structures. The individual material constituents should be selected considering spalling and strength loss. Figure( 2-10 ) presents a schematic for the two arguments of appropriate material choice ( Khoury, 2000 ).

 

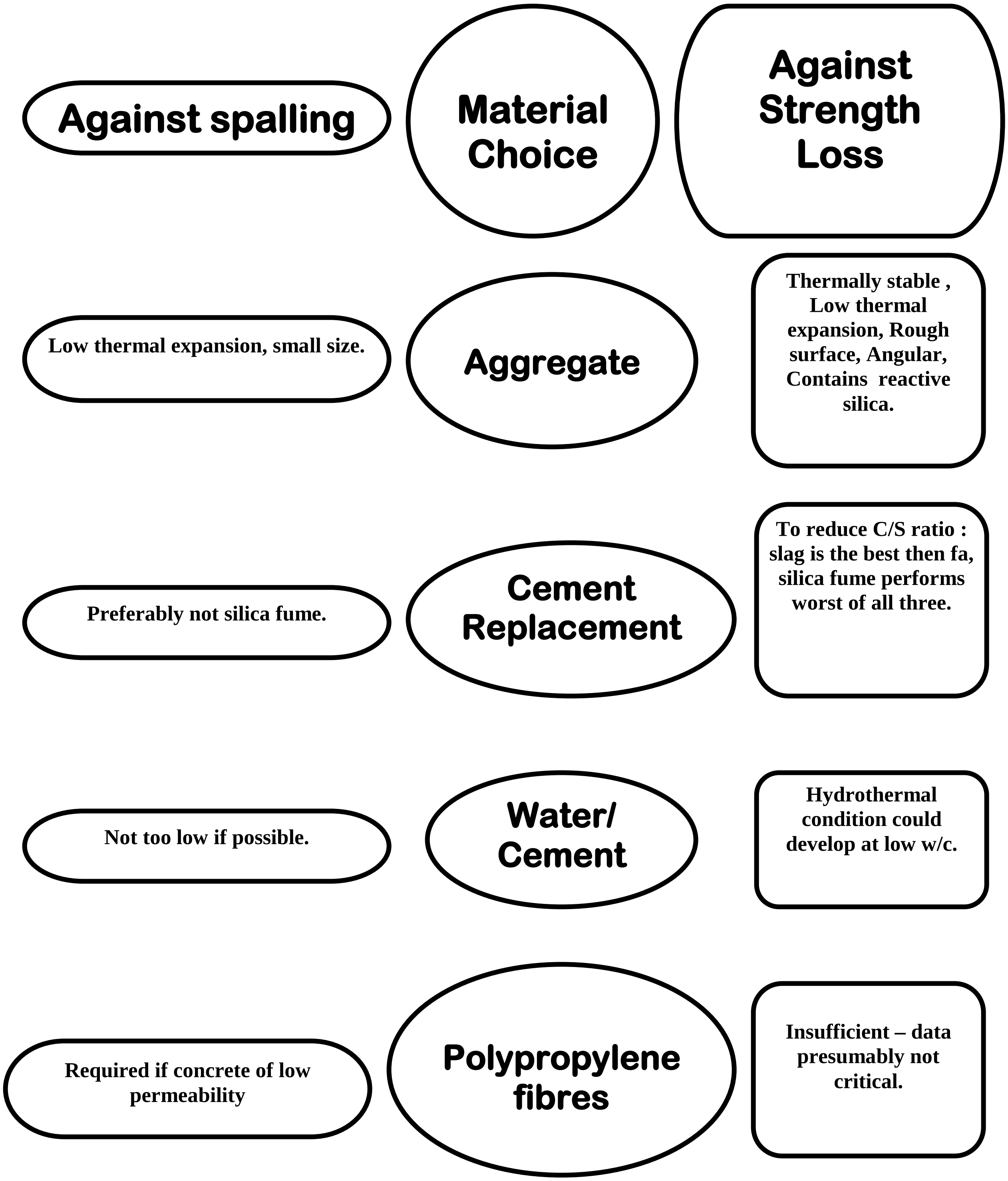


Fig. 1. Material choices for concrete under high temperature (Khoury, 2000).

(Habeeb , 2000 ) studied the effect of high temperatures ( up to 800 °C) on some mechanical properties of high strength concrete ( HSC ). Three design strength investigated 40, 60 and 80 MPa. The investigated properties were compressive strength, flexural strength and volume changes. Ultrasonic pulse velocity ( U.P.V ) and dynamic modulus of Elasticity ( Ed ) were tested also. The specimens were heated slowly to five temperatures levels ( 100 , 300 , 500 , 600 and 800 °C), and to three exposure periods 1.0,2.0 and 4.0 hours without any imposed loads during heating. The specimens were then cooled slowly and tested either one day or one month after heating. He concluded that the ( HSC ) is more sensitive to high temperatures than (NSC). The residual compressive strength ranged between (90-106 %) at 100 °C, ( 72-103 % ) at 300°C, ( 55-87 %) at 500°C and ( 22-66 %) between (600-80°0C). He concluded that exposure time beyond one hour had a significant effect on the residual compressive strength of concrete; however, the effect was diminished as the level of temperature increased. Moreover, the compressive strength at age of one month after heating, suffered an additional less than at age of one day after heating.The flexural strength was found to be more sensitive to high temperature exposure than compressive strength the residual flexural strength was in the range of ( 92- 98 % ) , ( 52- 98 %) and ( 29-47 % ) at 100 °C,300 °C, and 500 °C respectively and ( 2- 30% ) at (600- 800) °C. The author also noticed that the (U.P.V) and (Ed) were more sensitive to elevated temperature to exposure than compressive strength .

(Husem, 2006) examined the variation in compressive and flexural strengths of ordinary and high-performance concretes exposed to high temperatures of 200, 400, 600,
800 and 1000°C and then cooled in air or water. The compressive and flexural strengths of these concrete specimens were compared with each other and with unheated specimens. On the other hand, strength loss curves of these concrete specimens were compared with the strength loss curves given in the codes. In this study, ordinary concrete with an average compressive strength of 34MPa and high-performance concrete with an average compressive strength of 71MPa were produced. From the results obtained, he concluded that (a) for ordinary and high-performance concrete exposed to high temperature, the flexural and compressive strengths decrease with the increase in temperature. Such decrease is greater when the specimens were cooled in water. (b) the compressive strength of high-performance concrete cooled in air and water decreases up to 200°C and increases between 200 and 400°C. The compressive strength gain was 13% for the specimens cooled in air and 5% for those cooled in water. The compressive strength of ordinary concrete decreases continuously. (c) the compression test was not done on ordinary concrete at temperatures above 600°C, because the concrete specimens disintegrated. For high- performance concrete, the compression test was not done at temperatures above 800°C. (d) the concrete may completely lose its strength as a result of the immediate expansions that take place during the expansion of mineral admixture used in the production of high- performance concretes at high temperature. (e) it was observed that some high-performance concrete specimens spalled explosively at temperatures between 400 and 500°C, which is attributed to expansion of silica fume used in the production of such concretes. Explosive spalling was not observed for ordinary concrete specimens. (f) experimental studies indicated that ordinary and high-performance concretes produced using limestone aggregate underwent high percentages of strength loss in the specimens cooled in water after high temperature exposure. (g) The CEN Eurocode and the CEB design curves for the properties of fire-exposed concrete are not applicable to high strength concrete. The Finnish Code is more suitable especially up to 400°C. These codes are not applicable to ordinary and high-performance concrete cooled in water.

(Yeh, 2006), (Lee, 2003) and (Ahmet et al.,2006) applied the ANNs for predicting properties of conventional concrete and high performance concrete. (Kim et al.,2006) used back propagation neural networks to predict the compressive strength of ready mixed concrete. (Hola and Schabowicz, 2005) developed ANN model to predict the compressive strength of concrete on the base of non-destructive determined parameters. (Zarandi et al., 2008) applied the fuzzy polynomial neural network to predict the compressive strength of concrete.

Figure (2) presents typical multi-layer feed-forward neural networks used in the current application. This type of neural network consists of an input layer, one or more hidden layer(s) and an output layer. Layers are fully connected, as shown on Figure (1) by arrows, and comprises number of processing units, the so-called nodes or neurons. The strength of connections between neurons is represented by numerical values called weights. Each neuron has an activation value that is a function of the sum of inputs received from other neurons through the weighted connections (Haykin, 1999) and (Salim, 2007).

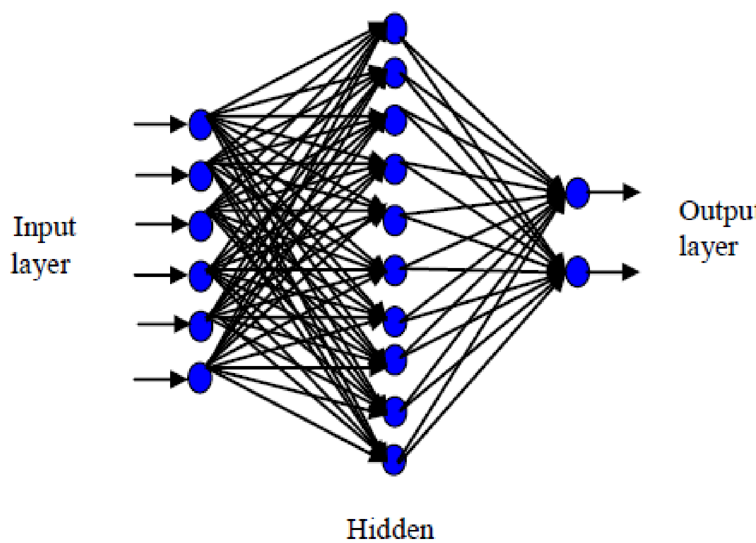

Fig. 2. typical form of neural network.

Experimental Work

**- Introduction**

The experimental work was carried out to decide upon the temperature range and duration of burning. It was decided to limit the maximum exposure to fire to about 300 °C, 550 °C and 750 °C with a duration of exposure to fire flame of 1.0 hour which cover the range of situation in the majority of elevated temperature test.

**- Material and Mixture properties**

In this investigation, the cement used Ordinary Portland Cement (O.P.C) produced at Kufa factory. This cement complied with the Iraqi specification No.5 (1984). The physical properties and chemical compositions are presented in Table(1). Crushed basalt (specific gravity of 2.65) having the maximum aggregate size of 10mm and river sand ( specific gravity of 2.62 ) were used as a coarse and fine aggregate content was 30% , by weight .

Three mixes were investigated mix 1 consisted 535Kg/m³of cement. In mix 2, 20% fly ash and 80% cement (O.P.C) (fly ash was replaced from cement). Mix 3 contained 90% (O.P.C) and 10% silica fume (silica fume was replaced from cement). For all three mixes the water to cement ratio was kept at 0.30, by weight. A constant dosage of super plasticizers ( 1.0 % by weight of cement ) was used in all concrete mixture to obtain workable concrete mixtures.

Table I

a- Physical properties of the cement

| Physical properties | Test results | IOS: 1984 limits |
|---|---|---|
| Fineness ,Blaine ,$cm^2/gm$ | 3190 | ≥ 2300 |
| he, vicat´s method initial hrs : min. final hrs : min. | 1:44<br>3:55 | ≥ 1:0<br>≤ 10:00 |
| compressive strength of70.7mm cube ,MPA | | |
| 3 days<br>7 days | 23<br>28 | ≥ 15<br>≥ 23 |

**b- Chemical composition of the cement**

| Oxide | % | IOS : 1984 limits |
|---|---|---|
| CaO | 61.11 | |
| $SiO_2$ | 19.80 | |
| $Fe_2O_3$ | 3.40 | |
| $Al_2O_3$ | 5.90 | |
| MgO | 4.14 | |
| $SO_3$ | 2.18 | ≤ 2.8 |
| Free lime | 0.71 | |
| L.O.I I.R. | 1.64<br>0.64 | ≤ 4.0<br>≤ 1.5 |
| **Compound composition** | **%** | **IOS : 1984 limits** |
| $C_3S$ $C_2S$ $C_3A$ $C_4AF$ L.S.F | 38.80<br>29.44<br>9.85<br>10.33<br>0.82 | 0.66-1.02 |

**- Concrete Mixing and Casting**

The concrete mixture were produced in a horizontal pan-type mixer of 0.1 m³ capacity.

The interior surface of mixer was cleaned and moistened before it was used. Freshly mixed concrete was tested for its density and used to cast a number of test specimens ( standard cubes , cylinder and prism ) in steel moulds. A table vibrator was used to achieve full compaction for the molded test specimens. The specimens used for compressive strength (150×150×150) mm cube and for tensile strength (100 mm diameter by 200 mm long) cylinder. The specimens used for flexural strength ( 100×100×400) mm prisms .

**- Burning and Cooling**

The concrete specimens were burn with direct fire flame from a net of methane burners inside a brick store with dimensions of (800×800×1000 mm) (length × width × height respectively) as shown in Plate (1). The bare flame was intended simulate the heating condition in actual fire. The measurement devices are shown in Plate (2). After burning, the concrete specimens were quenched in a water tank to provide the maximum thermal shock due to sudden cooling.

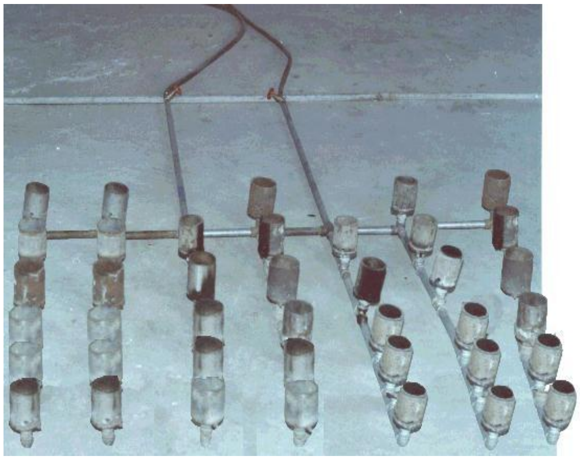

Plate (1): The work of net methane burners.

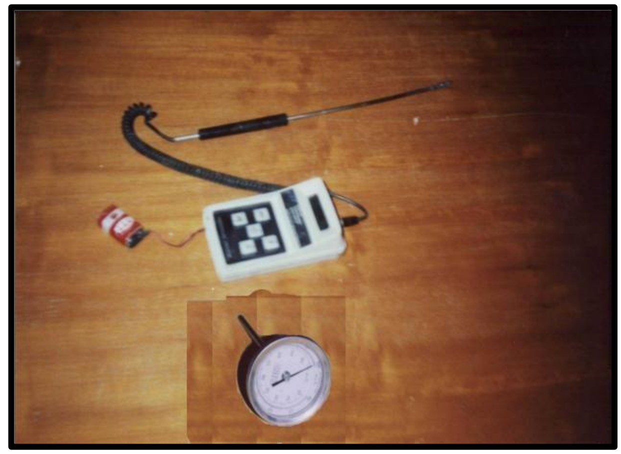

Plate (2) : Temperature measurements devices

**Results and Discussion**

**-The Density**

Table (2) show the effect of the exposure to fire flame on the density of high strength concrete, while Figure 3 shows the relations between the fire flame temperature and density with of high strength concrete . It can be seen from these Table and Figure that the density behaved for all burning exposure (300, 550 and 750°C) fire flame temperature exposure, the reduction in density was ranged between (1.8-2.8 %) , (3.6-5.5%) and (6.8-9.2%) respectively if compared with initial density before exposure to fire flame .These results confirmed that of ( Sri Ravindrarajah, 1993) and (Karim,2005).

Table II

Test values of density of high-strength concrete for all mixes before and after exposure to fire flame .

| Age at exposure (days) | Density ( Kg/m³ ) | | | | Ratios ρa / ρb | | |
|---|---|---|---|---|---|---|---|
| | Temperature °C | | | | | | |
| | 25 (a) | 300 (b) | 550 (c) | 750 (d) | b/a | c/a | d/a |
| 28 | 2645 | 2490 | 2350 | 2298 | 0.95 | 0.89 | 0.87 |
| 56 | 2634 | 2501 | 2350 | 2301 | 0.95 | 0.89 | 0.89 |
| 90 | 2628 | 2504 | 2354 | 2304 | 0.95 | 0.90 | 0.88 |

ρa = Density of concrete after exposure to fire flame.

ρb = Density of concrete before exposure to fire flame.

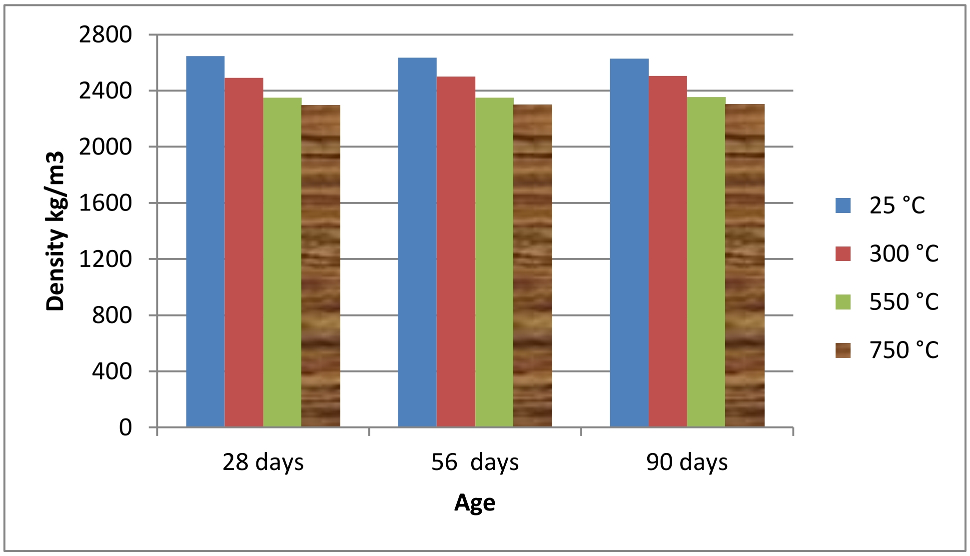


Fig. 3. The effect of burning on the density of high-strength concrete with age.

## Effect of Temperature on Compressive Strength

Compressive strength test was conducted by using a standard cubes of dimensions (150×150×150 )mm, each test was conducted by three cubes, some of the cubes were subjected to the fire flame and cooling, then they were tested at 28, 56 and 90 days age. The compressive strength results are summarized in Table (3), while the Figure 4 shows the relation between the compressive strength and fire flame temperature for different ages. The compressive strength of the high strength concrete dropped significantly as the maximum temperature was increased. The residual strength varied from (71-89%) of the corresponding initial strength when the concrete was exposed to the fire flame was 300°C followed by sudden cooling in water. As the temperature was increased to 550°C, the residual strength was ranged from (46-81%) of the initial strength. At 750°C fire flame temperature exposure the residual strength ranged from (29-45%) .

The results showed that the binder material type has noticeable influence on the residual strength. The concrete mixture containing silica fume performed poorly compared to other binder materials. Although the silica fume addition increased the initial strength of concrete, considerable compressive strength loss when exposed to fire flame temperature is noticed. These result agreed with that obtained by other investigations, (Habeeb,2000) and (Umran, 2002). It is observed that the color of the concrete specimens changed to pink and increased in intensity. This may be due to hydration condition of iron oxide component and other material constituents of the fine and coarse aggregates, (Habeeb, 2000). The surface cracks increased in number length and depth due to temperature rise.

Table III

Test values of compressive strength of high strength concrete for all mixes before and after exposure to fire flame .

| Age at exposure (days) | Compressive strength (MPa) Temperature °C | | | | Ratios fcua / fcub | | |
|---|---|---|---|---|---|---|---|
| | $25_{(a)}$ | $300_{(b)}$ | $550_{(c)}$ | $750_{(d)}$ | **b/a** | **c/a** | **d/a** |
| 28 | 58.0 | 50.0 | 44.4 | 24.6 | 0.86 | 0.76 | 0.41 |
| 56 | 60.8 | 53.3 | 48.2 | 26.8 | 0.88 | 0.79 | 0.43 |
| 90 | 62.2 | 55.2 | 50.6 | 28.6 | 0.89 | 0.81 | 0.45 |

fcua = Compressive strength after exposure to fire flame .

fcub = Compressive strength before exposure to fire flame.

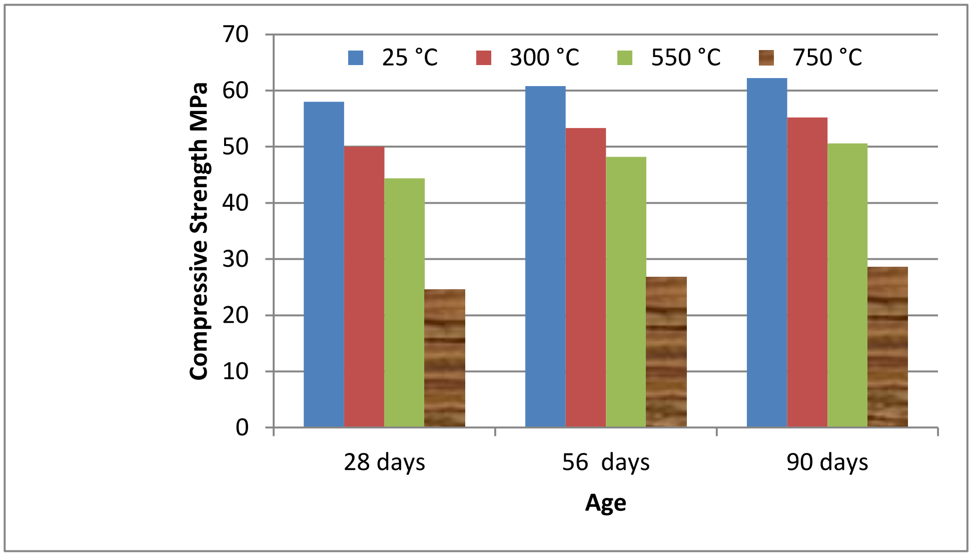


Fig. 4. The effect of burning on the compressive strength of high-strength concrete with age.

**Effect of Temperature on Tensile and Flexural Strengths**

The splitting tensile strength was performed by using a cylinders with dimensions (100×200) at 28, 56 and 90 days age, by applying the same procedure which used in the calculation of compressive strength, each test was conducted by three cylinders. Figure 4 reveals the residual tensile for high-strength concrete as a function of the maximum temperature. Similar to the compressive strength, the tensile strength showed significant losses with the increase in the exposed temperature. Once again, the binder material types played a noticeable role in influencing the strength losses. The results shown in Figure 5 indicated that the tensile strength having silica fume suffered significant loss in strength at the temperature of 550°C. The tensile strength for high strength concrete mixes was reduced by 78% to 84% when they were burn to 750°C. These result are summarized in Table 4.

Modulus of rupture was conducted by using (100×100×400 )mm high strength concrete prisms, and applying the same procedure which used in the calculation of compressive strength before and after exposure to fire flame, each test was conducted by three prisms. The flexural strength for the high strength concrete mixes are presented in Table 5, while Figure (6) represents the effect of burning fire flame exposure of flexural strength. Similar to compressive and tensile strengths of concrete, the flexural strength decreased with temperature. Once again the binder material type had influenced the extent of strength loss.

Table IV
Test value of tensile strength of high strength concrete for all mixes before and after exposure to fire flame.

| Age at exposure (days) | Tensile strength (MPa) | | | | Ratios Tsa/Tsb | | |
|---|---|---|---|---|---|---|---|
| | Temperature °C | | | | | | |
| | $25_{(a)}$ | $300_{(b)}$ | $550_{(c)}$ | $750_{(d)}$ | **b/a** | **c/a** | **d/a** |
| 28 | 6.88 | 6.40 | 6.00 | 5.47 | 0.93 | 0.87 | 0.79 |
| 56 | 7.30 | 6.62 | 6.22 | 5.90 | 0.90 | 0.85 | 0.80 |
| 90 | 7.40 | 6.92 | 6.52 | 6.10 | 0.93 | 0.88 | 0.82 |

Tsa = Tensile strength after exposure to fire flame. Tsb = Tensile strength before exposure to fire flame.

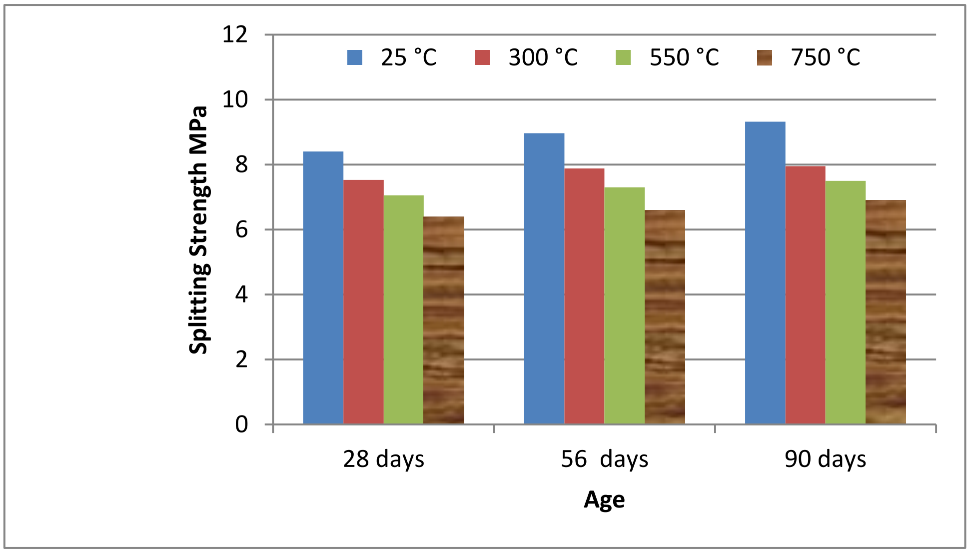


Fig. 5. The effect of burning on the splitting strength of high-strength concrete with age.

Table V

Test values of flexural strength of high-strength concrete for all mixes before and after exposure to fire flame.

| Age at exposure (days) | Flexural strength(MPa) | | | | Ratios Fsa/Fsb | | |
|---|---|---|---|---|---|---|---|
| | Temperature °C | | | | | | |
| | $25_{(a)}$ | $300_{(b)}$ | $550_{(c)}$ | $750_{(d)}$ | **b/a** | **c/a** | **d/a** |
| 28 | 8.40 | 7.52 | 7.05 | 6.40 | 0.89 | 0.84 | 0.80 |
| 56 | 8.96 | 7.88 | 7.30 | 6.60 | 0.87 | 0.80 | 0.73 |
| 90 | 9.32 | 7.95 | 7.50 | 6.90 | 0.87 | 0.81 | 0.75 |

Fsa = Flexural strength after exposure to fire flame . Fsb = Flexural strength before exposure to fire flame .

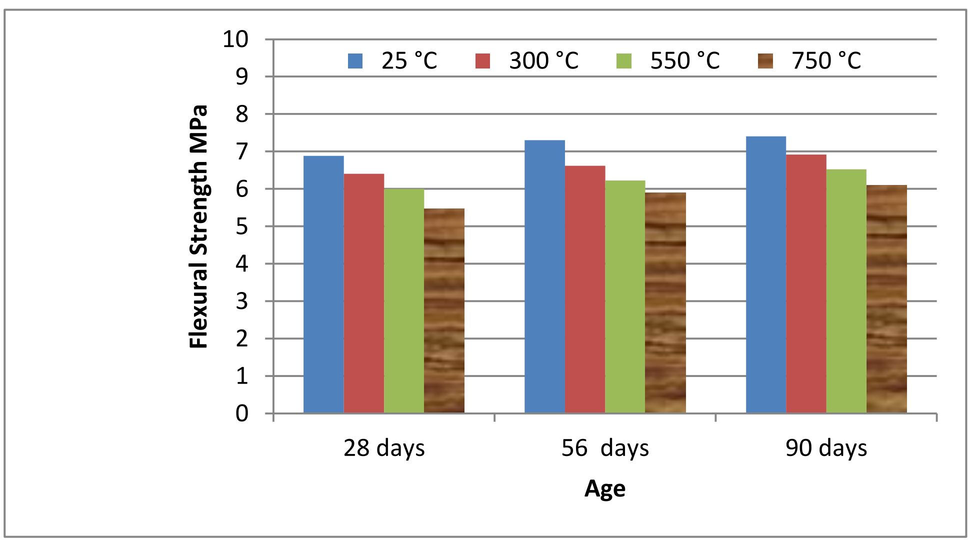


Fig. 6. The effect of burning on the flexural strength of high-strength concrete with age.

**Prediction With ANN for Some Mechanical properties of Concrete After Exposure to Fire Flame**

The first step in the development of the statistical analysis was the selection of the variables include in model prediction. The input and output variables were selected as shown in Table (6). ANN model developed in this research has three neurons in the input layer and one neuron in the output layer as illustrated in Figure 7. By using the data which was obtained from this study, mathematical models were proposed to predict the compressive strength of concrete after exposure to fire flame.

All results obtained from experimental studies and predicted by using the training and testing results of the ANN, for compressive were given in Figures 8 and 9.

As seen in Figures 8 and 9, good results were obtained from the multilayer feed-forward neural network model. The statistical parameter values of RMSE, $R^2$ and MAPE from training in the multilayer feed-forward neural network model were found as 0.3781, 0.986 and 0.02376, respectively for compressive strength.

The relative importance for various input parameters is shown in Figure 10 and the major dominant parameter is the temperature (63.9%).

Table VI
Dependent and independent variables using in ANN model.

| Output layers | Input layers |
|---|---|
| ***Fcua*** | ***fcub* , *Age, T, ρ*** |

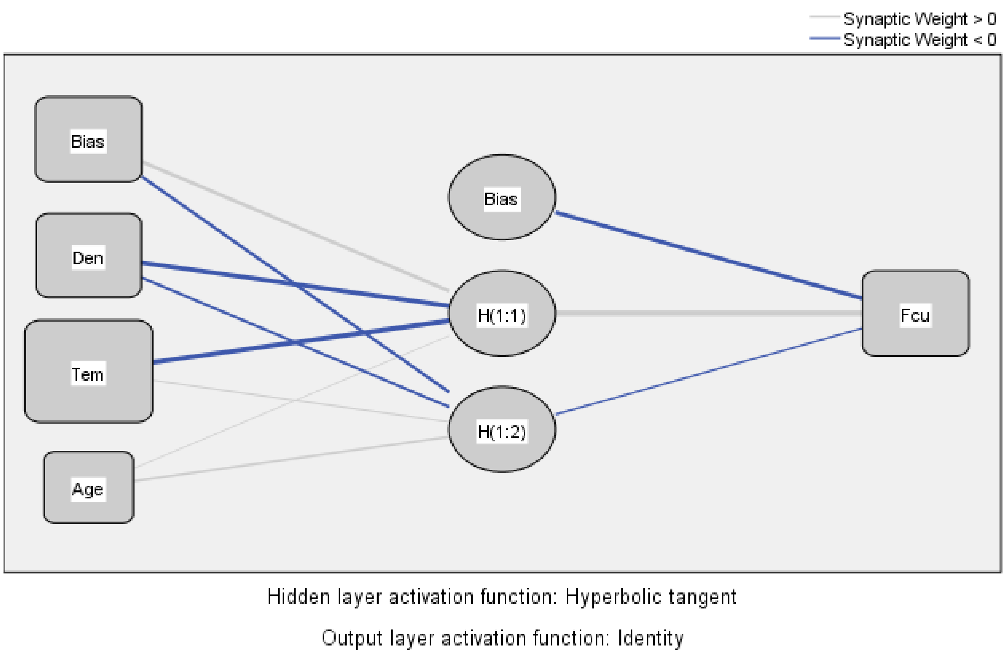


Fig. 7. Structure of the neural network for prediction of compressive strength of high strength concrete after burning.

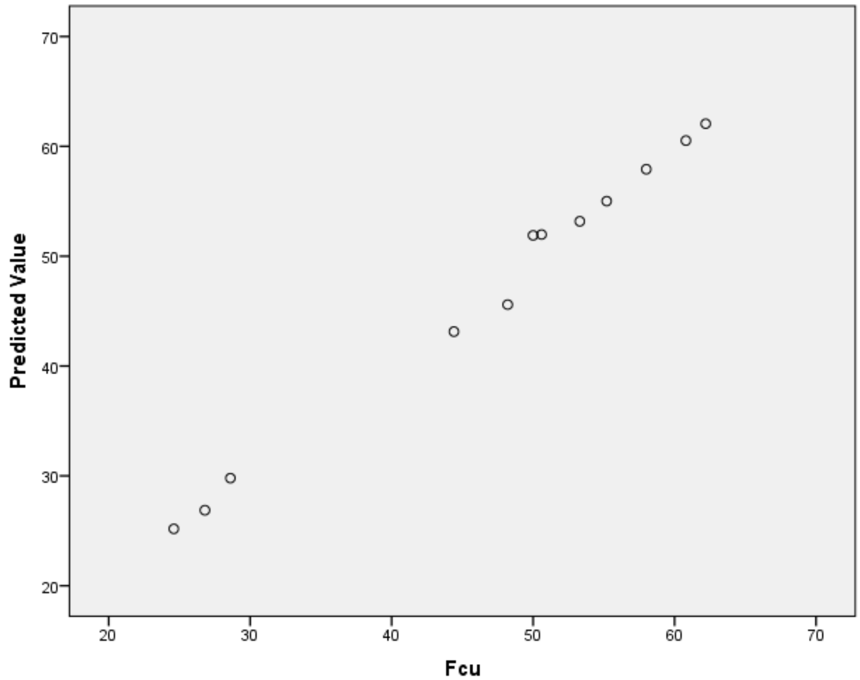


Fig. 8. The experimental values versus of the predicted values of high strength concrete after burning .

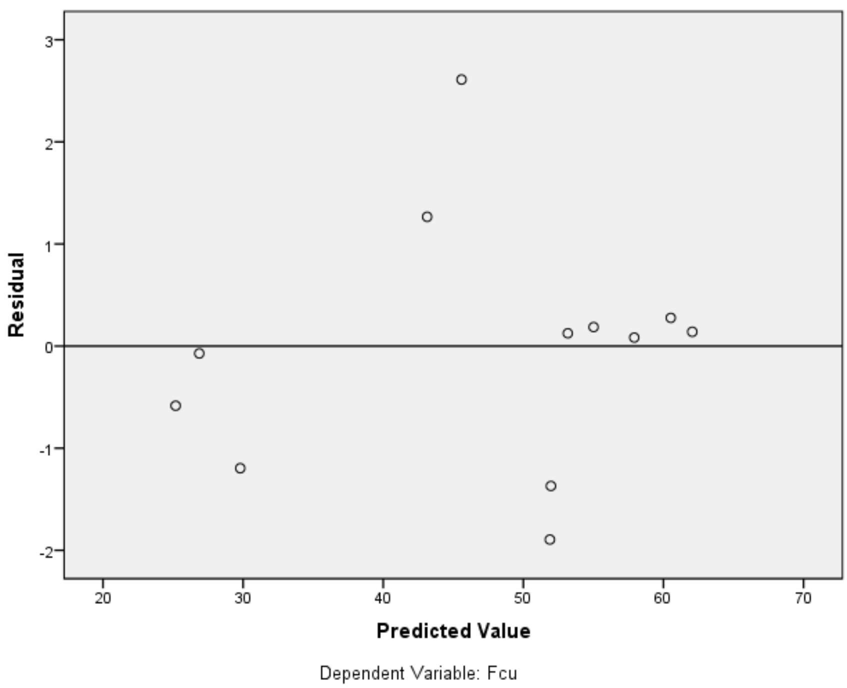


Fig. 9. The distribution of the residual values with predicted values of high Strength concrete after burning.

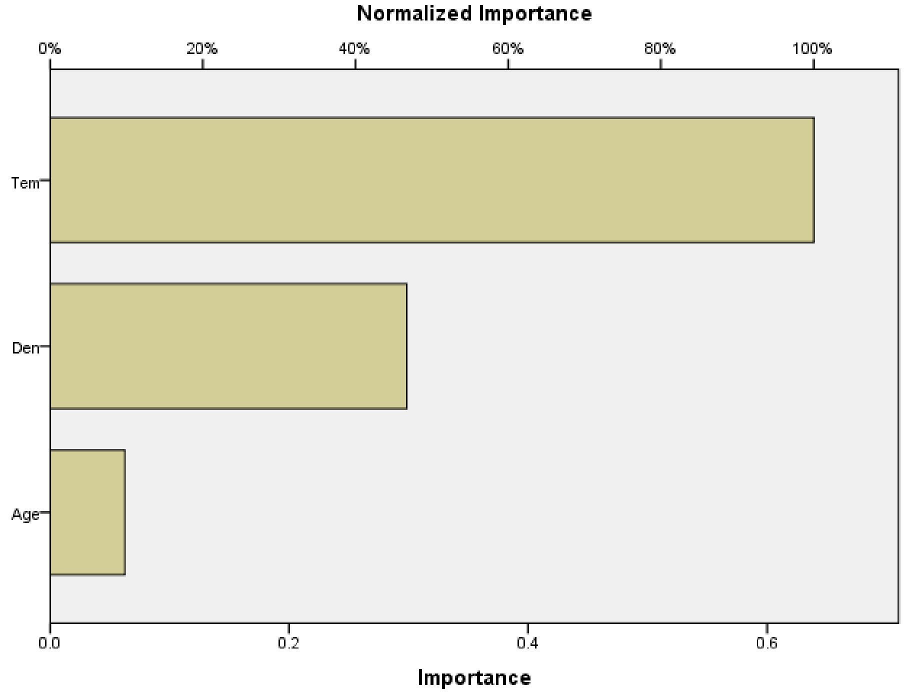


Fig. 10. Relative importance of input parameters for the prediction of compressive strength of high strength concrete after burning.

The best value of $R^2$ is 0.970 for testing set in the ANN model. The results obtained from experimental studies of some engineering properties of high strength concrete values before and after exposure to fire flame and the predicted values by ANN technique are presented in Table (7). It can be concluded from these results that the proposed multi-layer feed-forward neural network model is suitable and predicts compressive strength of high strength concrete after exposure to fire flame. Therefore, the following model could be used to estimate the compressive strength of high strength concrete after exposure to fire flame. The model was examined to predict of **$(f_{cu})_a$** after burning as follows:

$$f_{cua} = \exp\left(a \times f_{cub} - b \times Age - c \times T - d \times \rho + e\right)$$

Where:

***fcua*** = Compressive strength of the specimens after exposure to fire flame temperature, (MPa).

***fcub*** = Compressive strength of the specimens before exposure to fire flame temperature, (MPa).

***Age*** = The age of the specimens at the time of exposure (days).

***T*** **=** Temperature of fire flame (ºC).

ρ = Density of concrete before and after exposure to fire flame ($kg/m^3$).

Table VII
Test values of compressive strength of high strength concrete specimens before and after burning

| Age (days) | Temperature ºC | Density (kg/m3) | $(Fcu)_b$ (MPa) | $(Fcu)_a$_ANN (MPa) |
|---|---|---|---|---|
| 28 | 25 | 2645 | 58.0 | 57.9 |
| 28 | 300 | 2490 | 50.0 | 51.9 |
| 28 | 550 | 2350 | 44.4 | 43.1 |
| 28 | 750 | 2298 | 24.6 | 25.2 |
| 56 | 25 | 2634 | 60.8 | 60.5 |
| 56 | 300 | 2501 | 53.3 | 53.2 |
| 56 | 550 | 2350 | 48.2 | 45.6 |
| 56 | 750 | 2301 | 26.8 | 26.9 |
| 90 | 25 | 2628 | 62.2 | 62.1 |
| 90 | 300 | 2504 | 55.2 | 55 |
| 90 | 550 | 2304 | 50.6 | 52 |
| 90 | 750 | 2304 | 28.6 | 29.8 |

## CONCLUSIONS

Based on the results of this experimental the following conclusion can be made :

1- This study shows the feasibility of using the artificial neural networks (ANN) in building the model for predicting the compressive strength of high strength concrete after burning. The data were extracted from experimental tests conducted by Babylon University.

2- All mechanical properties of high strength concrete (compressive strength, splitting tensile strength, and modulus of rupture ) decreased when they were exposed to fire flame at 300°C, also they were decreased when the intensity of firing increased from moderate to high intensity.

3- Concrete with silica fume suffered the most under increased exposure to fire flame temperature below 750 °C.

4- High-strength concrete has shown 74% drop in its strengths once exposed to 750°C irrespective of the type of binder materials used.

5- For all the temperature levels, modulus of rupture (flexural strength) was more sensitive to fire flame than the others mechanical properties of high strength concrete.

6- The compressive, splitting tensile and flexural strength values predicted from testing, for the multilayer feed-forward neural network are very close to the experimental results than predicted values of regression model.

7- Based on experimental results, an equation to prediction the compressive strength of high strength concrete after burning was suggested as follows:

$$f_{cua} = \exp\left(\mathbf{a} \times \mathbf{f_{cub}} - b \times Age - \mathbf{c} \times \mathbf{T} - \mathbf{d} \times \rho + \mathbf{e}\right)$$

This equation gave a good agreement with the tested values in the experimental work.

## REFERENCE


[1] Shetty, M.S., (1988) , "Concrete technology" theory and practice" , third edition , 1988 pp.361.

[2] Malhotra ,H.L. (1956) " The effect of high-temperature on compressive strength " , magazine of concrete research , 8(3) pp.85 – 94 .

[3] Davis ,H.s (1967) ," Effect if high temperature exposure on concrete " material research and standards ,pp.452 – 459 .

[4] Abrams , M.S (1971), "Compressive strength of concrete at temperature to 1660f " , ACI special publication Sp25 , USA , pp.33 – 58 .

[5] FAiyadh ,F.I. and Al-Alusi ,M.A. (1989 ) , "Effect of elevated temperature on splitting tensile strength of fibre concrete ", the international journal of cement composite and light weight concrete , 11(3) pp.175 – 178 .

[6] Khoury ,G.A. (1992) ,"Compressive strength of concrete at high temperatures, a measurement " magazine of concrete research , 44(161) , pp.291 – 309 .

[7] Noumowe ,A.N. Clasters , P., Debicki ,G. and Boluin , M. ( 1994) , "High temperature effect on high performance concrete (70-600°C) strength and porosity ", ACI special publication SP145 , pp . 154 – 172 .

[8] Sri RAVIN Drarajah , R. and Stathopoulos , F. (1998) , "Residual compressive strength and tensile strength for high – strength concrete exposed to high temperature up to 800 °C " , proc .Int . conf . on high performance high strength concrete , Perth , Australia ,pp 663 – 645 .

[9] Habeeb ,G.M. (2000), "Residual mechanical properties of high strength concreted subjected to elevated temperature " , Ph .D. Thesis college of engineering , department of civil engineering , Al–Mustansiria University Baghdad , Iraq , November , 2000 , 164pp.

[10] Umran ,M.K. , (2002) , "Fire flame exposure effect on some mechanical properties of concrete " , M.Sc Thesis , College of engineering , University of Babylon October , 2002 , 103 pp.

[11] Karim, M.M. , (2005) ," Investigation of the behavior and properties of reinforced concrete slabes exposed to fire flame" , M.Sc thesis , college of engineering , university of Babylon , December , 2005 ,126 pp.

[12] Sri Ravin Drarajah , R. and mercer , C.M. ( 1993) , " properties of high – strength concrete containing cement Supplementary materials " , proc . FIP congress ,Kyoto , Japan.

[13] Husem, M. (2006) "The Effect of High Temperature on Compressive and Flexural Strengths of Ordinary and High-Performance Concrete" Fire Safety Journal 41:155- 163.

[14] Sanad, A., and Saka, MP., "Prediction of Ultimate Shear Strength of Reinforced-Concrete Deep Beams Using Neural Networks", Journal of Structural Engineering, ASCE, Vol. 127, No. 7, pp.818–828, 2001

[15] Jung, S. and Ghaboussi, J., "Neural Network Constitutive Model for Rate-Dependent Materials", Computers and Structures, Vol. 84, pp 995-963, 2006.

[16] Salim T. Yousif, "Artificial Neural Network Modeling of Elasto-Plastic Plates", Ph.D. thesis, University of Mosul, Iraq, pp. 1-198, 2007.

[17] Yeh, I. C., "Analysis of Strength of Concrete Using Design of Experiments and Neural Networks", Journal of Materials in Civil Engineering, ASCE, Vol. 18, No. 4, pp. 597-604, 2006.

[18] Lee, S. C., "Prediction of Concrete Strength Using Artificial Neural Networks", Engineering Structures, Vol. 25, pp. 849-857, 2003.

[19] Ahmet, O., Murat, P., Erdogan, O., Erdogan, K., Naci C. and Asghar, B., "Predicting the Compressive Strength and Slump of High Strength Concrete Using Neural Network", Construction and building materials, Vol 20, pp, 769-775, 2006.

[20] Kim, J. I., Kim, D. K., Feng, M. Q., and Yazdani, F., "Application of Neural Networks for Estimation of Concrete Strength", Journal of Materials in Civil Engineering, ASCE, Vol. 16, No. 3, pp. 257-264, 2004.

[21] Hola, j. and Schabowicz, K., "Application of Artificial Neural Networks to Determine Concrete Compressive Strength Based on Non-Destructive Tests", Journal of civil Engineering and Management, Vol. XI, No. 1, pp.23-32, 2005.

[22] Zarandi, M. H., Turksen, I. B., Sobhani, J., and Ramezanianpour, A. A., "Fuzzy Polynomial Neural Network for Approximation of the Compressive Strength of Concrete", Applied Computing, Vol. 8, pp. 488-498, 2008.

[23] Haykin, S., "Neural Networks a Comprehensive Foundation". 2nd ed., Prentice Hall, New Jersey.