Experimental and Theoretical Investigation of the Physical Properties of new Composite Materials

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Abstract. The Experimental and theoretical investigation of the physical properties of new composite materials were studied by conjugating two materials. One of them is the strong virgin polymer (Commercial HDPE powder) high density polyethylene and the other is the scrap of tire tubes polyisobutylene. By application thermal insulation materials and introducing them to the building market during the last decades can give the same thermal resistance a thinner construction using. The preparation of specimens from a composite of high-density polyethylene and the scrap of tire tubes [3x5] mm with different weight ratios from 0 % to 55% were adapted. Both of mechanical and thermal conductivity to measure and estimate the modulus of elasticity, shore hardness, impact strength and thermal conductivity for the various prepared polymeric specimens. The optimum thermal insulation was obtained with 40% weight of the scrap of tire tubes and 60% HDPE, the optimum thermal conductivity showed a value of 0.078 W/m. K which is less than the other composite samples. In addition, the theoretical study by the neuro fuzzy models are developed to predict the physical properties (elastic modulus, thermal conductivity, shore hardness and impact strength) of the composite materials using fuzzy logic toolbox in the Matlab version 7.10. Different membership functions and adaptive neuro fuzzy inference systems (ANFIS) are used in these models. The selected input variables used in the proposed models include HDPE and the scrap of tire tubes. During the test of neuro fuzzy model good agreements and observed.

Keywords: useless tire tubes, Lee’s disk, Neuro-Fuzzy model

1. Introduction
The mechanism of heat transfer in solid materials depend on increases the kinetic energy of electrons, by atoms vibration in a crystalline form and vibration and impact of molecules by themselves. For this reason polymers are more suitable in case of their large molecules with more difficult vibration , that means the molecule chains absorb energy vibration in large amounts to reduce the molecules impact between them .So polymers posses low thermal conductivity [1], that means a suitable suggestion for insulator materials is the porous polymers, which are part of heterogeneous materials such as granular porosity like powder materials high density polyethylene (HDPE) .Reducing the heat transfer is the major purpose for adding thermal insulation, where a suitable insulation inserted to thermal conduction largely, therefore thermal conductivity coefficient makes a major criteria in the choice of insulations .For the prepared composites, the thermal radiation and convection can be neglected because the irradiative and convective properties are inversely proportional to pore diameter of the solid cells [2] and as the polymer composites mixture was fabricated using combined heating compression under a load of (100-120)Pa and a temperature of (175-180)C for 30 minutes .The pores are used hot valid in the prepared composites process. Thermal conduction is related to the materials, the cross sectional area for heat flow through the sample and the distance of travel from the hot to the cold side of the solid materials. Hamilton and Crosser, [3], had performed an experimental
investigation of thermal conductivity of two-component heterogeneous mixture, consisting of balsa wood particles of several shapes as a discontinuous phase, and silastic rubber as a continuous phase. The same method was applied for Aluminum particles in rubber. Chung, Masahito and Takao, [4], had investigated theoretically and experimentally the thermal conductivity of polyurethane foam in the temperature range, between room temperature at 300 K for the development of liquid hydrogen storage tank. An experimental setup based on the JIS standard A 1412 was built to measure the thermal conductivity of foams under various temperature and pressure. Garcia et al., [5], had studied polypropylene – SiO2 nanocomposites using two different inorganic fillers, colloidial (solution) and powder silica nanoparticles, let to different micro structures when compared with the pure polymer. They found that when powder silica was added to the pure polymer led to the increase of both Young modulus and impact strength from 1.2 GPa to 1.6 GPa and from 3.4 kJ/m² to 5.7 kJ/m² respectively. Tavman, [6], had studied the thermal conductivity of nanometer sized particle and fiber filled polymer composites and a model predicting the effective thermal conductivity of composites filled with particles. He obtained that the material possessed good properties are thermal, mechanical and electrical. Suryasarathi et al., [7], prepared particulate reinforced thermoplastic composites to improve the properties and to lower the overall cost of engineering plastics. They investigated the effects of adding mica with variable particle sizes on the mechanical and thermal properties of nylon-6. using twin screw extrusion, the composite showed improved mechanical and thermal properties on the addition of a filler and improve these properties with the decrease in particle size that depends strongly on size, shape and distribution of filler particles in the matrix polymer and good adhesion at the interface surface. Wang et al., [8], had studied and determined the effects of pre-treated flux fibers on the performance of the fiber-reinforced composites, lack of good interfacial adhesion and poor resistance to moisture absorption make the use of natural fiber-reinforced composites less attractive. In order to improve fiber/matrix interfacial properties, these composites consisted of HDPE or LLDPE or HDPE/LLDPE mixed, the samples of fiber and additives were prepared by the extrusion process and rotational molding. They investigated the effects of the different chemical treatments on the mechanical and thermal properties, and using Differential Scanning Calorimetry (DSC) to measure the melting point of the fiber reinforced composites. Duncan and Mark, [9], suggested to study thermal conductivity of Polytetrafluoroethylene. (PTFE) using an apparatus called Lee’s disk, and incorporating fillers into a PTFE/glass fiber, the effect of crystallinity on thermal conductivity was studied and different methods of crystallinity determination were compared. They found that thermal conductivity of PTFE with different levels of crystallinity was measured at 232 °C increase linearly with this parameter. Axel and PÅR [10] noticed the porous composite materials, such as mineral wool and expanded polystyrene (EPS), for building applications decreased the thermal conductivity from 14-16 mW/(m K) to 4 mW/(m K). Alok A. and Alok S.[11] chose Epoxy and polypropylene as matrix materials, with conductive fillers as aluminum nitride (AIN) and aluminum oxide (Al2O3) and insulative fillers as pine wood dust (P WD) and rice husk (RH). They measured values of thermal conductivity were then compared with the values obtained from the proposed mathematical model for 0–15 vol% filler concentration. It was encouraging to notice that the measured values were in close approximation with the values predicted by the proposed model. Yuan et al. [12] obtained graphene-epoxy thermal conductive adhesive using few-layers of graphene sheets as additives which were fabricated by the re-expansion and exfoliation method. The experimental results showed that graphene sheets could effectively enhance the thermal conductivity of epoxy matrix.

Over the last few years some function approximation techniques such as artificial neural networks (ANN) was employed to approximate the mechanical properties instead of direct implementation [13,14,15,16]. However, the adaptive neuro-fuzzy inference system (ANFIS) had been widely used for different purposes such as prediction [17]. In the present study, The preparation of specimens from a composite of high density polyethylene and the scrap of tire tubes with different weight ratios, both of mechanical and thermal conductivity tests were evaluated, a new application of ANFIS model is used to analyze the mechanical properties of the prepared new composite materials. The individual effects of adding each of useless tube tire ratios to HDPE on the mechanical properties for the new composite materials are studied. The results obtained from this model are compared with experimental tests. The results reveal the efficiency of the suggested approach for best analysis. The aim of the present work
deals with manufacturing of useful materials from wastes as a friendly to the environment by recycling the scrap of tire tubes and to reduce the effective cost of insulation materials energy used for heating the buildings.

1- Estimated elastic modulus: The calculated elastic modulus for the specimens using the equation below [18] is:

\[ \log (E) = 0.0235 \times \text{Sh} - 0.6403 \]

Where Sh: Shore hardness for specimens [19].

2- Impact strength: The impact strength which is the ability of the polymer to absorb applied energy, or ability to resist the fracture under the stress applied at high speed [20]. A notch creates a localized stress concentration and the part fails under impact loading [21]. In order to specify the toughness of the presented specimen their impact strength was measured by implementation of the Izod testing method. The fracture force was recorded and the impact strength was calculated by the following relationship, [1].

\[ \sigma_I = \frac{E_I}{A} \]

where
\[ \sigma_I: \text{Impact strength (kJ/m}^2\text{)} \]
\[ E_I: \text{Impact energy (kJ)} \]
\[ A: \text{Area under the notch (m}^2\text{)} \]

3- Lee’s disk method: The sample used to measure the thermal conductivity at BS 4745 using Lee’s disk method [22], is in the form of a disk whose thickness is small relative to its diameter.

\[ K = K' \frac{d(T_2 - T_0)(T_1' - T_2'}{d'(T_2 - T_0')(T_1' - T_2'A)} \]

To calculate the thermal conductivity for every thermal insulator, using the equation above when limiting the value of thermal conductivity \( (K') \) for the standard insulator- poly methyl metha acrylate (PMMA).

4- Adaptive Neuro-Fuzzy Inference System (ANFIS): The adaptive neuro-fuzzy inference system, first introduced by Jang [23], has implemented Takagi–Sugeno fuzzy rules. Where the given data are such that the system associates the measurable system variables with an internal system parameter, a functional mapping may be constructed by ANFIS that approximates the process of estimation of the internal system parameters [24]. Therefore neural network learning concepts have been incorporated in the fuzzy inference systems. So the network is “learning” the behavior of the available data during the training phase by adjusting the parameters of the node functions to fit that data. The basic learning algorithm, the back propagation, aims to minimize a set measure or a defined error, usually mean square error [25]. ANFIS can be constructed as a five layer MLP network, with the following layer operations: (1) Layer 1: generate fuzzy membership values for an input variable, (2) Layer 2: multiply the incoming signals from the previous layer and estimation of the firing strength of each rule, (3) Layer 3: computes the normalized firing strength, (4) Layer 4: node k in this layer calculates the contribution of the \( (i) \)th rule in the model output based on the first-order Takagi–Sugeno rules, and (5) Layer 5: calculates the weighted global output of the system. In this model the Back-Propagation (BP) algorithm is used to modify the initially chosen membership functions and the Least Mean Square (LMS) algorithm determines the coefficients of the linear output functions. The ANFIS implemented in the Fuzzy Logic Toolbox of MATLAB is used in the present study. In the developed ANFIS, two variables the useless tire tubes and HDPE are selected as input variables to predict the physical properties Elastic modulus, thermal conductivity, shore hardness and impact strength, which are the variables. In this investigation the curse of dimensionality technique with (genfis1) function and
different membership functions (Gaussian and Generalized bell) are used. In the fuzzy inference system, the space is basically partitioned into three types of input, grid, tree, and scattering [26]. GENFIS1 uses the grid partitioning and it generates rules by enumerating all possible combinations of membership functions of all inputs; this leads to an exponential explosion even when the number of inputs is moderately large. For instance, for a fuzzy inference system with 2 inputs, each with five membership functions, the grid partitioning leads to 25 (=5^2) rules, which is inhibitive large for any practical learning methods. The "curse of dimensionality" refers to such situation where the number of fuzzy rules, when the grid partitioning is used, increases exponentially with the number of input variables [26].

2. Materials Used
The materials used are the useless tire tubes polyisobutylene (UTT) structurally is produced by polymerization of about 98% of isobutylene with about 2% of isoprene and high-density polyethylene (HDPE).

3. Instruments Used
The instruments used are Shore D Hardness, Impact charpy tester, thermal conductivity measurement tester.

4. Experimental work & results
Specimen preparation: It was planned to mix pieces of the UTT (useless tire tubes) at an area of (5x3) mm² as the additive material with different ratios (0,5,15,25,30,35,40,45,50,55) % to high density polyethylene then molding the composite materials by a thermal press (100-120) Pa at a temperature of (175-180) °C for 30 minutes which are shown in Table 1. In this research, it is quite useful to determine the mechanical and thermal properties of composite materials.

| Sp.No. | 1   | 2    | 3   | 4    | 5    | 6    | 7    | 8    | 9    | 10   |
|--------|-----|------|-----|------|------|------|------|------|------|------|
| HDPE % | 100 | 95   | 85  | 75   | 70   | 65   | 60   | 55   | 50   | 45   |
| UTT %  | 0   | 5    | 10  | 15   | 30   | 35   | 40   | 45   | 50   | 55   |

4.1. Shore Hardness
This method can be used to estimate the hardness values for plastics. The shore D method is used according to the ASTM D2240, with the following specifications:

. MFG-company, Inc., U.S.A.
. Indenter diameter = 0.1 ± 0.01 mm
. Max load = 50 N

An average of five measurements is shown in Table 2, which was made for each test composite.

| Sp.No. | 1   | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   |
|--------|-----|------|------|------|------|------|------|------|------|------|
| Average Shore hardness | 25  | 38   | 34   | 30   | 28   | 26   | 24   | 22   | 20   | 18   |
| ± Error | 5   | 4    | 3    | 2    | 2    | 1    | 1    | 1    | 1    | 1    |

4.2. Impact strength
The impact strength is one of the important destructive parameters for measuring the toughness of materials; these measurements are shown in Table 3 using the charpy test. Compression molding of the samples were prepared to satisfy the ASTM D256 standard size conditions, AV-notch with an angle of 45⁰ and depth of 2.5mm was made for each sample using the notching machine (TMI notch
cutter model 43-15-1). The average five of specimens was prepared from each composite by a Charpy testing method.

Table 3: Impact strength testing results of the specimens.

| Sp.No. | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 |
|--------|----|----|----|----|----|----|----|----|----|----|
| Average Impact strength J/m² | 59 | 76 | 68 | 60 | 56 | 52 | 58 | 56 | 40 | 36 |
| ± Error | 2  | 4  | 3  | 4  | 1  | 1  | 5  | 1  | 1  | 1  |

4.3. Elastic Modulus
The theoretical elastic modulus for composite materials is shown in Table 4.

Table 4: Elastic modulus of the specimens.

| Specimen No. | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     | 9     | 10     |
|--------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|
| Elastic Modulus (MPa) | 0.94  | 1.287 | 1.172 | 1.066 | 1.017 | 0.971 | 0.926 | 0.884 | 0.843 | 0.804   |
| ± Error      | 0.00  | 0.037 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000   |

4.4. Thermal Conductivity
This test was carried out in accordance with BS 4745 to determine the optimum thermal conductivity coefficient by Lee’s disk method. The results are shown in Table 5.

Table 5: Thermal conductivity testing results of the specimens.

| Specimen No. | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     | 9     | 10     |
|--------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|
| Ther.con. W/m °K at 24 °C | 0.163 | 0.121 | 0.108 | 0.095 | 0.118 | 0.083 | 0.078 | 0.128 | 0.064 | 0.057   |
| ± Error      | 0.003 | 0.002 | 0.002 | 0.003 | 0.001 | 0.002 | 0.002 | 0.001 | 0.002 | 0.002   |

Figure 1: Shore hardness as a function of useless tube%.
Figure 2: Impact strength as a function of tire useless tire tube%.
5. Modeling and Results

5.1. Membership Functions (MFs)
For ANFIS analysis, types and number of MFs assigned to each input variable are decided by a trial and error. Figure 5, shows the final membership functions for all input variables: i) useless tire tube % –5 Gaussian MFs, ii) HDPE – 5 Gaussian MFs of four properties. The final MFs on input variables are not symmetric due to identifying the consequent parameters by the least squares method and updating the premise parameters by the gradient descent method. Most data in the database has membership grades between 0 and 1 for linguistic terms.

6. Training and Testing Results
A comparison between the predictions from ANFIS and measured ones from experimental tests are shown in both training and testing data sets of four mechanical properties in Figure 6. The results appear to be good enough to have more than 0.99 of correlation R even though there are a few bit scatters in the testing data points. The comparative analysis of testing period performance of the neuro-fuzzy technique using root mean-squared error (RMSE) has been carried out and it is shown in Figure 5. According to the ANFIS model Figure 5, the RMSE values include shore hardness, impact strength, thermal conductivity and Elastic modulus respectively. In this work, the neuro-fuzzy model provided the best performance, i.e., the lowest RMSE and highest R, for the testing periods. Also, it can be seen that the modeling results are reasonably in good agreement with the results for all data sets and also show that the predicting ability of ANFIS is excellent.
Figure 6: Comparison of experimental (target) and predicted values for training and testing data set of four mechanical properties. a) training, b) testing (Model 1)

Figure 7: RMSE (Root Mean Square Error) curves for experimental (target) and predicted (ANFIS) of the four physical properties.

The present study for the physical properties to obtain a suitable thermal insulator from HDPE and useless tire tube at different percentages include measuring the mechanical properties such as Shore hardness, impact strength, elastic modulus and thermal conductivity. The variation of Shore hardness, impact strength and elastic modulus with the (0,5,15,25,30,35,40,45,50,55)% useless of tire tube ratios are presented in figs. 1,2,3. It can be noticed that Shore hardness, impact strength and elastic modulus increase at 5% useless tire tube then decrease with the increase of useless tire tube percentage. So the first stage increase of Shore hardness, impact strength and elastic modulus, due to the restricted movement of chains and the specimen in the hard state. The second stage showed that Shore hardness, impact strength and elastic modulus are decreasing because of the high ratio of useless tire tubes and the soft nature of this material, which lead to making leathery state of the specimens and decrease the shore hardness, impact strength and elastic modulus. Figure 4 showed the variation of thermal conductivity with the useless tire tube, and it was noticed that is a decrease in the values as a result of decreasing vibration of molecules of thus reducing the thermal conductivity due to increasing the weight of chains and restricted the chains movement. But there are two values of thermal conductivity (0.118 & 0.128) W/m.°K at (30 & 45)% of useless tire tubes respectively higher than other values but still less than the value of thermal conductivity of a virgin specimen. So, the prepared
composite showed high thermal insulator values which can be used in different thermal insulator applications.

Figure 5 shows that the ANFIS can be used for predicting the physical properties for new composite materials. The neuro-fuzzy model is more flexible with more options of incorporating the fuzzy nature of the real-world system. The adaptive neuro-fuzzy inference system approach provides a general framework for the combination of neural networks and fuzzy systems capabilities. The adaptive neuro-fuzzy models perform more useful estimation tool for the physical properties. This conclusion has been supported by the values of RMSE and R which are global, more realistic and meaningful error types, namely, the lowest RMSE and the highest R (more than 99% of correlation), in the ANFIS technique were achieved.

7. Conclusion
From the results obtained from the present investigation the increasing useless tire tubes percentage lead to increasing thermal insulation. A decreasing impact strength when increasing filler content. The thermal insulator produced in this work has a very low thermal conductivity (0.0572 W/m. °K) in comparison to the virgin polymer (0.163 W/m. °K) as in Table 5, and average the Shore hardness values decreases to 30% with an increasing UUT% content.

8. References
[1] JABAR, A.R.,"Preparation and Evaluation of Some Thermal Insulators of Polyethylene & Polyester by the Addition of Asbestos" MSc.thesis, Basra, Iraq, 2007.
[2] Hans-Peter, Heinemann, U., Heat-Transfer Mechanisms in Polyurethane Rigid Foam, High Temperature, High Pressure, Vol. 33, pp. 699-706, Germany, 2001.
[3] Hamilton, R.L and Crosser, O.K, "Thermal conductivity of heterogeneous Two-component systems", Ind., and Eng. Chem. Fundamentals, Vol. 6, part3, pp. 187-191, 1992.
[4] Chung, H.W., Masahito, Y. and Takoo, O.," Thermal conductivity of polyurethane foams from Room Temperature to 20 K", Advanced Technology Department, Research Institute, Japan, 1997.
[5] Garcia M, G. Van Vliet, S. Jain, B. A. G. Schrauwen, A. Sarkissov, W.E Van zyl, B. Boukamp, "Poly propylene/Sio2 Nanocompoites with improved mechanical Properties", Rev. Adv. Mater. Sci., Netherlands, 2004.
[6] Tavman I.H," Thermal conductivity of particle Reinforced polymer composites" Mechanical Eng. Dep., Dokuz Eylul University, Turkey, 2004
[7] Suryasarthi Bose, P.A. Mahanawar, " Effect of particle size of filler on properties of Nylon-6", Journal of Minerals and Materials characterization and Eng., Vol.3, No. 1, PP. 23-31, India , 2004.
[8] Wang B., S. Panigrahi, L. Tabil, W. Crerar, "Pre-treatment of Flax Fibers for use in Rotationally Molded Biocomposites", Journal of reinforced plastic and composites, Vol. 26, No. 5 , pp. 447-463 , Canada, 2007.
[9] Duncan M. Price, Mark Jarratt, "Thermal conductivity of PTFE and PTFE composites", UK, 2002.
[10] Axel B., PÅR J. " Report of High Performance Thermal Insulation "Chalmers University Of Technology Gothenburg, Sweden, 2012.
[11] Agrawal A. and Satapathy A."Mathematical model for evaluating effective thermal conductivity of polymer composites with hybrid fillers" International Journal of Thermal Sciences, Vol.89, pp. 203–209. 2015.
[12] Yuan-Xiang Fu, Zhuo-Xian He, Dong-Chuan Mo, and Shu-Shen Lu "Thermal conductivity enhancement of epoxy adhesive using graphene sheets as additives"International Journal of Thermal Sciences, Vol. 86 pp. 276–283. 2014.
[13] Vikrant Gupta, and etc., ANFIS Prediction of the Polymer and Polymer Composite Properties and Its Optimization Technique ,IJRSET, Vol.4, 580-593. 2015.
[14] Seyhan G., G. Tayfur, M. Karakurt & M. Tanoglu, Artificial neural network (ANN) prediction of compressive strength of VARTM processed polymer composites. Computational Materials Science, No. 34, pp. 99-105 (2005).

[15] Roy N. K., D. P. Landau, and W. D. Potter, Designing Polymer Blends Using Neural Networks, Genetic Algorithms and Markov Chains, Applied Intelligence, 20(3), pp. 215-229. (2004).

[16] Singh R., P.K. Sharma and R.S. Bhoopal, Prediction of Effective Thermal Conductivity of Cellular and Polymer Composites. Indian Journal of Pure Applied Physics, Vol. 49, No. 5, pp. 344-349. (2011).

[17] Bhoopal R.S., P.K. Sharma, S. Kumar, A. Pandey, R.S. Beniwal and R. Singh, Prediction of Effective Thermal Conductivity of Polymer Composites Using Artificial Neural Network Approach. Special Topics & Review in Porous Media—An International Journal, Vol. 3, No. 2, pp. 115-123. (2012).

[18] Jump up to: "Shore (Durometer) Hardness Testing of Plastics" Retrieved, 2006.

[19] Deanin, R.D., "Polymer structure, properties and application", Cahnees publishing Co. P.171, Boston, 1972.

[20] Dubois, j.H, Levy, s., "Plastic product design engineering handbook", Reinhold, PP. 104-105, New York, 1977.

[21] Vincent, P.I., "Impact Tests and service performance of thermoplastics", the plastic institute, P.12, London, 1971.

[22] Lees Disk,"for the measurement of the thermal conductivity of a poor conductor such as a polymer", 2002

[23] Jang, J. S. R., ANFIS: Adaptive Network-basel Fuzzy Inference Systems, IEEE Transactions on Systems, Man and Cybernetics, Vol.23,665–685. 1993.

[24] Kisi, O., Suspended sediment estimation using neuro-fuzzy and neural network approaches”, Hydrol. Sci. J. Vol. 50 (4), 683–696. 2005.

[25] Vassilopoulos, A., and Bedi, R., Adaptive neuro-fuzzy inference system in modelling fatigue life of multidirectional composite laminates, Comp. Mater. Sci.Vol.43, 1086–1093. 2008.

[26] Alavandar, S., and Nigam, M. J., Adaptive Neuro-Fuzzy Inference System based control of six DOF robot manipulator, Journal of Engineering Science and Technology Review, Vol. 1, 106-111. 2008.