A Study of Some Mechanical, Thermal and Physical Properties of Polymer Blend with Iraqi Kaolin Filler

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Abstract

In the present work, polymer blends were fabricated by mixing two polymers of polypropylene and poly (methyl methacrylate) mixed in different weight percentage and different particle size of Iraqi kaolin. The study of some mechanical, physical and thermal conductivity properties was carried out on all composites. The mechanical tests included (impact, hardness, modulus of elasticity, yield strength, elongation, stress at break and compression), Lee's disc method was used to calculate the coefficient of the thermal conductivity of specimens before and after reinforcement with kaolin powder. The physical properties test included absorption tests, as well as X-ray measurement. The results have shown that after the reinforcement with different weight percent of kaolin powder, most mechanical properties such as hardness , modulus of elasticity and compression increase while impact and elongation decrease with increasing in weight percentage and a decreasing in particle size. The results have shown also that the coefficient of thermal conductivity decreases with increase weight percentage the water gain is decreased with the increase in weight percent and decrease in particle size of the filler. X-ray diffraction pattern of filled samples indicates that addition of kaolin adversely affects the crystallization of PP/PMMA blend.

Keywords: PP, PMMA, Blend, Filler, Kaolin , Mechanical ,Thermal, Physical Properties.

دراسة بعض الخواص الميكانيكيةالحرارية والفيزياوية لخليط بوليميري باستخدام الكاؤلين القراني كمادة مالئة

الخلاصة

في البحث الحالي تم تحضير مزيج من نوعين من النسب الوزنية من البوليمرات (البولي بروبلين و البولي ميثامثيل اكريليت) مع نسب وزنيه و حجوم حبيبية مختلفِة مِنْ الكاولينِ العراقي، وبعد ذلك جرت دراسة بعض الخواص الميكانيكية والفيزياوية والحرارية والفحص باشعة اكس ولجميع المتراكبات المحضرة. شملت الفحوصات الميكانيكية تتضمن فحوصات (الصدمة والصلادة والانضغاطية والشد) . الفحوصات الحرارية تضمنت استخدام قرص لي لحساب معامل التوصيل الحراري للنماذج قبل وبعد التدعيم بمسحوق الكاؤلين. الفحوصات الفيزياوية تضمنت الامتصاصية والذي جرى عند نسب مختلفة من مادة الكاؤلين لدراسة تاثيرها على تلك الخواص. فحص اشعة اكس لمعرفة تاثير اضلفة مادة الكاؤلين على التركيب البلوري للمادة المتراكبة. النتائج بينت انه بعد التدعيم بمختلف النسب الوزنية والاحجام المختلفة من مادة الكلؤلين فان اغلب الخواص الميكانيكية ماعدا اختبار الصدمة ونقطة الخضوع ازدادت مثل (الصلادة, معامل المرونة) مع زيادة نسبة الكاؤلين وصغر حجم الدقائق. وكذلك النتائج اظهرت انه بعد التدعيم بمسحوق الكاؤلين فان معامل التوصيل الحراري تقل مع زيادة نسبة الكاؤلين وصغر الحجم الحبيبي. اما الامتصاصية فانها قلت مع زيادة النسبة الوزنية لمادة الكاؤلين

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وصغرحجم الحبيبات لتلك المادة. اما تاثير اضافة الكاؤلين على التركيب البلوري للمادة المتراكبة فانها تؤدي الى انخفاض النسبة البلورية للمادة المتراكمة.

1. Introduction

Fillers are very widely used in the plastics industry, and their growth rate currently exceeds those of the resins themselves. Fillers are used in polymers for a variety of reasons: cost reduction, improved processing, density control, optical effect, thermal conductivity, control of thermal expansion, electrical properties, magnetic properties, flame retardancy and improved mechanical properties, The use of fillers enables commodity thermoplastics, such as polypropylene, to achieve cheaply the same levels of performance that would otherwise require much more expensive engineering plastics. Mineral fillers such as carbon, calcium carbonate, China clay, feldspar, silica, talc and wollastonite, chopped glass fibers are classified as fillers, together with solid glass and polymer beads, glass and metallic flakes, and hollow micro spheres [1].

Fillers with hydrophilicity or polarity and the polymer with polar groups facilitate surface bonding because the surface of the filler can be easily wetted by a polymer. Therefore, whether or not the polymer molecule has polarity is an important parameter in determining the reinforcement effect of polymer composites. Mechanical bonding between polymer matrix and filler offers good bonding of constituents. In order to have a good interface adhesion between polyolefin's and filler, it is necessary for this kind of plastic to bear the polarity before a good affinity with fillers. PMMA is a brittle plastic. Chain stiffness comes in the filled polymer due to absorption of the chains as the filler surface. This change in the chain mobility of surface layer is attributed to formation of hydrogen bond between filler surface and functional group of polymers. Incorporation of glass beads has reduced the molecular motion of PMMA.

Polypropylene (PP) is a commercially important polymer, which is of practical use in a wide range of applications; its morphology [2,3] means that the mechanical properties of PP are moderate, so if one wants to extend the field of application of this material, an improvement of the mechanical properties is usually necessary. Sumiata studied the effect of ultra fine particles on the elastic properties of PP composite, he proved that the fine spherical particles in various diameters were mixed with PP. Young's modulus of composites filled with proportionally small particles increased with increasing filler content and with decreasing filler size, whereas those of the composites filled with large filler decreased with increasing filler
content and size [4] .

Maiti, and Chawla studied the tensile properties of Polypropylene/Kaolin Composites. Tensile properties of isotactic polypropylene filled with particulates of kaolin fillers were evaluated in the composition range (0-60)wt % kaolin. Tensile modulus increased with filler concentration while breaking elongation and tensile
strength decreased [5].

Lisaka and Shibayma, studied the effect of filler particle
size on dynamic mechanical properties of Poly (methyleth-acrylate)

(PMMA).With increasing particle size, dynamic modulus (E) slightly decreases for glass bed system(G)[6].

Lee, and Jang**,** studied the preparation and characterization of PMMA-clay composite by emulsion polymerization. They showed that the elongation at break decreases with increasing clay content, and increases in the stress at break showed by filled polymers [7].

Mohamed Baker, Katarzyna Skrzypek, studied the effect of kaolin and Polyurethane on the Fracture and Thermal Properties of Epoxy Based Compositions. It was shown that the impact strength of epoxy resin increased with polyurethane (PU) content significantly until it reached a maximum value of 5.8 kJ/m2 at 20 phr kaolin and 6.9 kJ/m2 with 20 phr of PU, which corresponds to respectively 150 % and more than 200 % improvement in comparison with IS of neat resin. The addition of 5 phr – 20 phr PU did not affect KC but this latter decreased with 30 phr or 40 phr PU. However, KC was maximally increased by appro-ximately 60 % with 20 phr kaolin and 40 % with 20 phr PU.

The thermal resistance of epoxy resin decreased by 40 % with the addition of 10 phr PU, however the addition of both modifier, i.e. 15 phr kaolin and 10 phr PU leads to an increase of DTUL the level of that of virgin epoxy resin[8].

Balamurugan et al, studied the development and Spectral Characterization of Poly (methyl-methacrylate)/Hydroxyapatite Com-posite for biomedical applications. The synthesized composite was characterized using spectral techniques [9]. Suryasathi et al. studied the effect of fly ash on the mechanical, thermal, dielectric, rheological and morphological properties of filled nylon (6).showed improved mechanical, thermal as well as electrical properties on addition of filler. It is also observed that mechanical properties, electrical properties as well as thermal properties increase with decrease in particle size [10]. Navin, and Vashishtha, studied development, structure and strength properties of PP/PMMA/FA blend. Addition of fly ash imparted dimensional and thermal stability, which has been observed in scanning electron micrographs and in TGA plot. Increase in fly ash concentration increases the initial degradation temperature of PP/PMMA blend. The increase in thermal stability has been explained based on increased mechanical interlocking of PP/PMMA chains inside the hollow structure of fly ash [11]. Dr. Najat j. Saleh Development and study properties of PP/PMMA /Bentonite Blend Addition of filler increases the young modulus and tensile strength at break [12]. L. Domka A. Malicka, and N. Stachowiak studied the Production and Structural Investigation of Polyethylene Composites with Modified Kaolin.

The results were compared to those obtained for the composites with unmodified filler and pure HDPE. [13]. Aim of the work In this study:

1. We have developed a new type of PP/PMMA blends of filled with local Iraqi Kaolin as filler.
2. Study &determining mechanical physical and thermal properties of filled and unfilled PP/PMMA blend.
3. Study the effect of particle size of filler on the mechanical (strength) thermal & structure of blend and correlated this variable to find an empirical correlation.

In the present work, the mechanical, physical and thermal properties of PP/PMMA blends have been investigated. Also samples of different particle sizes (40, 60, 80, 100, and 120) µm of filler (locally) were prepared; the effect of change in the percentage of kaolin on mechanical, physical and thermal properties was quantitatively analyzed.

2. Experimental

2.1. Materials

Commercial grade isotactic polypropylene (PP) was supplied by SABIC Saudi Arabia;

Commercial grade a tactic poly (methyl methacrylate) (PMMA) was supplied by M/S Monika plastic, India.

Kaolin clay has a density of 2.64 g/cm³ .Iraqi kaolin which produce from Dawakhla location by Iraqi National Company for Geological Survey and Refinery.

2.2. Methods

PMMA, PP and kaolin samples were dried in an air circulating oven at 70°C for 24 h to dry the materials. Weighed amounts of materials were mechanically mixed, various compositions were prepared of (PP/PMMA) blend and kaolin wt% concentration. Also samples of different particle sizes (40, 60, 80, 100, 120) µm of filler (kaolin) were prepared.

This mixture was then fed into 25 mm single screw extruder. The barrel temperature was monitored and controlled by thermostat. The die temperature was also controlled by a thermostat and was adjusted, together with barrel temperature to yield uniform output. feed, compression and metering zone temperatures were Zone1(190 ^{o}C) Zone2 (220 ^{o}C) Zone3 (240 ^{o}C) and Die (220 ^{o}C).

The extruder produced 2 mm diameter monofilament which was cooled in air. The monofilament produced by using a screw speed of (20 r.p.m.) was uniform and opaque; it was cut in the form of granules of (3- 4)mm length. The sheet was prepared by hot pressing the granules between hydraulic press at 200°C for PP/PMMA/Kaolin. A pressure of 20 kg/cm^2 was applied for 5 min. to allow the composite to melt and spread out between plates. Pressure was then increased to 200 kg /cm^2 for further 5 min. After the pressure was removed the mold sheet was quenched in water at room temperature. Composite materials consist of two or more physically distinct and mechanically separable components called reinforcement and matrix.

These two components can be mixed in a controlled way to achieve optimum properties, which are superior to the properties of each individual component.[16]. Tensile testing measurements were done according to ASTM 638[17] on tensile testing machine (Zwick Universal Model 1434) at room temperature. A cross head speed of 10 mm/min was used. Charpy impact instrument was used in this test.

The samples were prepared according to ASTM (D256-87) [17]. Hydraulic piston type Leybold Harris No. 36110 was used in compression test of the polymer materials. The test was carried out according to the test specification of ASTM (D695)[17]. Lee's disk instrument was used to determine the thermal conductivity. The disk was of diameter equal to (40mm) and thickness range between (2-4) mm (ASTM-D570) [17,18].

X-ray phase analysis of the prepared samples was done on Phillips X-ray diffraction type (PW). Recorded

intensity values in the range between 10-60°, 2θ angle value it was carried out in Iraqi National Company for Geological Survey.

The amounts of water absorption of all the composites at room temperature were calculated according to the following equation (1) [19].

$$M_t(\%) = \frac{wt - wo}{wo} X100 \quad \ldots\ldots (1)$$

where Mt is the amount of water absorbed at time t and w_t and w_o are the weight of the sample at time t and the initial weight of the sample, respectively.

Absorption test in water was carried out on samples with the thickness of 3mm which were immersed in water for different periods of time and samples were reweighed after immersion for 2,3,24 hours 2,3,4,5,6, and 7days ,then using Fick's second law diffusion coefficient was determined for a composite material The moisture absorption curve is plotted on the graph and the linear portion is determined by assuming that the curve ceases to be linear after 60% of the maximum moisture content is reached. Here the maximum moisture content is the same as the highest moisture content reached for the specimen exposed to the harshest environment. Thus the slope of the curve is found and the diffusion coefficient (D) was calculated using the following equation [19, 20]:

$$D = \pi[K\, b/4Mmax]^2 \quad \ldots\ldots\ldots\ldots (2)$$

where:

D: diffusion coefficient (m^2/sec)

K:the slope of the curve of $(t)^{0.5}$ with weight gain (%)

b: sample thickness (m)

% Mmax: variation in weight gain.

4. Result and Discussion

4.1 Modulus of Elasticity

It was also seen that modulus of elasticity increased with an increase in concentration of filler loading in both the cases whereas the rate of increase in modulus of elasticity was higher when smaller particle size kaolin was used. It was observed that modulus of elasticity increased and attained maxima at lower filler concentration when smaller particle size kaolin was used as compared to larger particle size kaolin. This may have been due to agglomeration of smaller particle size kaolin after certain concentration. In the case of larger particle size wide particle size distribution the smaller filler particles occupied the interstitial volume and hence the surface area available for deformation force was higher in the case of a smaller particle size than that of larger particle size wide particle size distribution material. The phenomenon of agglomeration and surface area of filler available was also confirmed by early onset of modulus of elasticity decreasing in the case of smaller particle size kaolin as compared to larger particle size kaolin. It was also clear that at higher concentration the modulus of elasticity was almost same in both of the cases, which may be due to insufficient matrix available for encapsulating individual filler particles and agglomerates. The modulus of elasticity increased continuously with increasing concentration of filler loading of both the smaller and larger particle sizes where as at higher loading for larger particle size the values of modulus of elasticity was more than that of smaller particle size filler indicating phenomenon of agglomeration of smaller particle size filler than that of larger particle size filler. The modulus of elasticity was reduced by addition of higher concentration of filler (30%) for larger particle size where as in case of

smaller particle size the modulus of elasticity continued increasing thereby indicating that the saturation level of filler matrix composition was influenced by agglomeration. The trend of variation of modulus of elasticity of different particle sizes of kaolin with varying concentrations is presented in Figure (1). The result obtained agrees well with that obtained by Sumiata [4].

4.1 Tensile Strength at break and Elongation

It was observed that as the concentration of filler increased tensile strength at break decreased. The rate of decrease of tensile strength at break was higher when larger particle size was used. It was also observed that the percentage elongation decreased drastically on addition of filler in both the larger and smaller particle sizes of kaolin but the rate of change of percentage elongation with varying percentage of filler was higher in the case of smaller particle size as compared to larger particle size of kaolin. It was also seen that at higher filler loading the reduction of tensile strength at break was higher in case of larger particle size.

The rate of reduction of percentage elongation was higher in case of smaller particle size up to 20% filler loading whereas, it was higher at higher filler loading in case of larger particle size kaolin. This variation may have been due to wide particle size distribution of larger particle size kaolin than that of smaller particle size kaolin and at higher filler loading the interstitial volume must have been occupied by smaller particles as filler and there may have been an insufficient matrix available for contributing to the percentage of elongation. The trend of variation of tensile strength at break and percentage of elongation of different particle sizes of kaolin with varying concentration is presented in Figure 2 and Figure 3 respectively. These results are in good agreement with results obtained by Maiti and Chawla [5]

4.2 Yield Strength

From Figure (4) it is clearly seen that a decrease in the yield strength is obvious in filled polymers. It is also obvious that with the addition of such a low content of kaolin filler weight fraction and different particle sizes the yield strength decrease with increase in weight percent and increase in particle size and this may be due to the decrease in binding forces between the matrix and the filler. The results agree well with results obtained by Ahamd [21], and Abed Al-hakem [22], they found that the effect of weight percent and particle size of filler on yield strength of composite filled with small particles decreases with increasing filler content and with increase in filler size, whereas those of the composites filled with large filler decrease with increase in filler content and size.

4.3 Impact Strength

The impact strength decreased with increasing conc-entration of filler in the case of larger particle size kaolin whereas in case of smaller particle size the impact strength initially increased or remained almost same up to 10% filler loading, which confirmed the void space available in the larger particle size material and thereby demonstrated that stress propagation was greater in the case of a larger particle size filled composites than that of a smaller particle size composites.

The impact strength values of higher filler loading composites (10 wt%) of smaller particle size as well as that of larger particle size kaolin

with the same filler loading were almost identical, which indicated the agglomeration of smaller particle size filler and thereby generated increasing void space, which was responsible for stress propagation. It was also observed that rate of change of impact strength was same at higher filler loading i.e above 10 wt% of both the particle sizes and this indicated that the total surface area available for matrix remained almost same in case of both the larger particle size and smaller particle size agglomerates. The trend in variation of impact strength of different particle size kaolin with varying concentration is presented in Figure 5 and Figure 6.

These results agree well with results obtained by Navin and Vashishtha[10] and Abed Al-Hakem [22]. A further increase in weight percentage of filler reduces the deformability of the matrix and in turn reduces the ductility in the skin area so the composite tends to form a weak structure [10].

4.4 Shore Hardness

It is clearly seen from Figure (7) that the hardness increases with decrease in particle size and increase in weight percent of filler. The addition of kaolin filler increases the hardness of composite material due to increase in the resistance strength of polymer to plastic deformation. The results agree well with those obtained by Navin and Vashishtha [10] and Abed Al-hakem [22].who showed in his research that the hardness increases with increasing weight percent and decrease in particle size.

4.5 Compression Strength

It is clearly seen from Figure (8) that the compression strength increases with increasing weight fraction and decreasing particle size of kaolin filler. The result agrees well with results obtained by Abed Al- hakem [22] who illustrated showed in his research that the compression strength increases with increasing weight percent and decreasing particle size]. The results agrees well with results obtained by Navin and Vashishtha [11]

4.6 Thermal Conductivity Test

Figure (9) illustrates the variation in thermal conductivity of sample with varying filler percentage. It is clear from this Figure that the thermal conductivity of PP/PMMA sample decreases steeply with the increase in filler loading and filler size. Thermal conductivity of kaolin is dominated by phonon transport. In unfilled samples moderate to high values are observed for thermal conductivity samples as a result of strong covalent bonding between the atoms. Thus increase in phonon means free path of samples. As the percentage of filler increases the phonon transport decreases and consequently the thermal conductivity decreases. Lower particle of kaolin resulting in higher thermal conductivity. This is attributed to the increase in interstitials volume or the increase in matrix filler surface contact [23, 24].

4.7 Absorption Test

All polymers absorb moisture in humid atmosphere and when immersed in water. Absorption processes often follows the predictions of Fick's law. Figure (10) shows the relation between the weight gain with the square root of time for immersion of filled and unfilled PP/PMMA blend for different particle sizes of kaolin filler. From the Figure, it is clearly seen that the weight gain increases and decreases weight percent, and weight gain decreases with decrease in particle size of filler. The absorption percent is reduced with increase in the weight fraction of filler, which increases the ability of polymeric

composite material to bear water during service life. The amount of water absorbed will depend primarily upon the chemical nature of the polymer matrix and the environment to which it is exposed. Water absorption causes swelling of the polymer and also acts as plasticizing factor and as such will lower the glass transition temperature (T_g) [24-26].

It is clearly seen from Figure (11) that the coefficient of diffusion will increase with decrease in particle size of the filler. The water absorption was reduced by addition of higher concentration of filler above (10%) for larger particle size where as in case of smaller particle size the water absorption continued decreasing thereby indicating that the saturation level of filler matrix composition was influenced by agglomeration. The trend of variation of water absorption of different particle sizes of kaolin with varying concentrations is presented in Figure **(**10). The structure of kaolin is not symmetrical the crystal layers become highly crystals allows the kaolin to absorb water molecules (which are also polar) between the layers. Kaolin exists natural in the hydrous from crystal structures that are linked together by hydroxyl containing moieties

These results agree well with those of [24-26].

4.8 X-ray Analysis

Figures (12) and (13) illustrate the X-ray diffraction pattern of PP/PMMA (80/20) Wt % and PP/PMMA/kaolin (76/19/5) Wt%, The characteristic intensity peaks of PP are recorded at (13.8, 16.4, 18.3, 21.4, 22.1, 23.8, 25.2, 28, and 42.3) 2θ values and the calculated d. spacing of(6.38, 5.38, 4.86, 4.18, 3.68, 3.51, 3.15 and 2.12) (Angstrom). The diffraction pattern of PP/PMMA filled with kaolin exhibits all reflections of PP/PMMA blend along with the addition of kaolin peaks at (4.4, 3.56, 2.88, 2.56 and 3.37) Angstrom Figure (13) It can be observed that the addition of kaolin modifies the intensities of peaks of the crystalline PP/PMMA polymer present in the matrix. The peak intensities for PP/PMMA of (5.38, 4.86 and 4.18) Angstrom are reduced from (5000 to 4823, 3901 and 4450) respectively. This may be explained by the fact that addition of kaolin adversely affects the crystallization of PP/PMMA by increasing the discontinuity and therefore restricts the growth of crystals in the blend composites filled with the kaolin.

5- The Analysis of Empirical Correlation

The experimental results of this study are used to develop empirical correlation. The statistical program was used on high-speed personal computer (Pentium 4). The method of developing the present model is by introducing equations of different forms in the computer program. The calculated values of the dependent variable(Y) are compared with the actual value (observed) and the procedure is repeated until excellent agreement is obtained.

The dependent and indep-endent variables were introduced into the computer program in such a way that the developed models could be used to find the change in mechanical properties for the composite material. The independent variables, affect the mechanical properties of the PP/PMMA/kaolin blends Equations (1) to (8) shown in Table (1), represent the developed models for the modulus of elasticity, tensile strength at break, yield strength, elongation, shore hardness, comp-ression strength, impact strength, thermal conductivity

with weight percent of filler and different particle sizes.

Statistical analysis of developed modules is given in Table (2) which includes the values of correlation coefficients. Figure (14). includes the experimental and model data which is in excellent agreement. The results can be presented in terms of three dimensional representation and contour plots as shown in Figures (15) and (16).

The practical use of such contour plots, it gives directly the value of property without need of experimental data. Content needed to attain that value of properties can be directly obtained from the plots. That is the procedure optimizes the value of the variables needed to get any desired value of the properties.

6-Conclusions

At the end of this study about polymeric reinforced with mineral clay some conclusions are reached:

1. The addition of mineral clay (kaolin) was found to improve the modulus of elasticity, stiffness, hardness.
2. The impact test shows that the impact strength of PP/PMMA blend slightly decreases after reinforcement with kaolin filler.
3. The coefficient of thermal conductivity of PP/PMMA blend decreases with increase in weight percent kaolin filler, and decreases with a decrease in particle size.
4. The mechanical property can be represented as simulation function of two variables (weight percent of filler content and particle size) by second degree polynomial equations, and these equations show the best fit with experimental data. A relevant contour diagrams based on the proposed equation, of optimization of properties is also presented.
5. The matrix absorption of water decreases after reinforcement with kaolin filler and increases in weight percent and a decrease in particle size.
6. X-ray diffraction pattern of filled samples indicates that addition of kaolin adversely affects the crystallization of PP/PMMA blend.

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Table (1)General properties of the Isotactic polypropylene

General properties	Value
Density, g/cm³	0.908
Melt flow index (MFI) g/10 min	11
Molecular weight of repeat unit g/mol	42.07
Tg °C	0 <
Tm °C	170
Degree of crystalline %	50 - 70

Table (2) General properties of the poly methyl methacrylate

General properties	Value
Density, g/cm³	1.19
Molecular weight of repeat unit g/mol	100
Tg °C	105
Tm °C	225
Degree of crystalline %	64 - 69

Table (3) Chemical composition of kaolin clay

Sio2	AL2O3	Fe2O3	TiO2
52.48	31.31	2.094	1.43
MgO	Na2O	CaO	L.O.I
0.33	0.28	0.462	10.93

Table (4) General properties of Kaolin

properties	Quantity
Density, g/cm³	2.64
Powder color	white
Melting point °C	1755
Fracture resistance fracture	high225
Thermal properties	Endothermic at 260 °C
	Isothermic at 980 °C

Table (5) Composition of kaolin filled PP/PMMA blend

No.	Composition (g)		
	PP %	PMMA %	Kaolin %
1	80	20	0
2	76	19	5
3	72	18	10
4	68	17	15

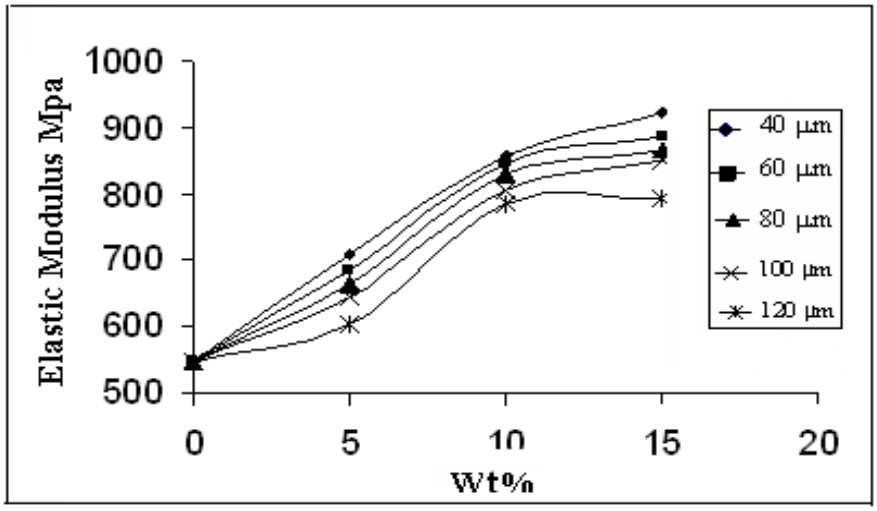

Figure (1) the relation between the tensile modulus of PP/PMMA and weight percent of kaolin filler for different particle sizes

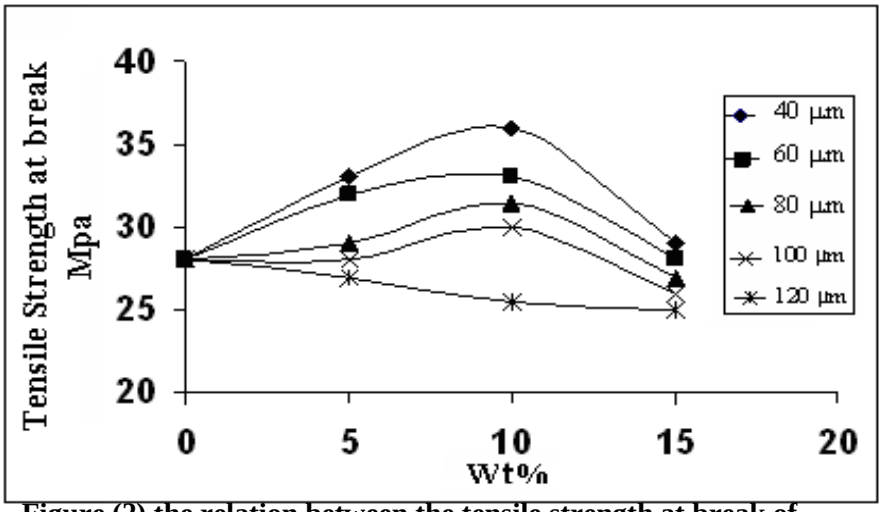

Figure (2) the relation between the tensile strength at break of P/PMMA and weight percent of kaolin filler for different particle sizes

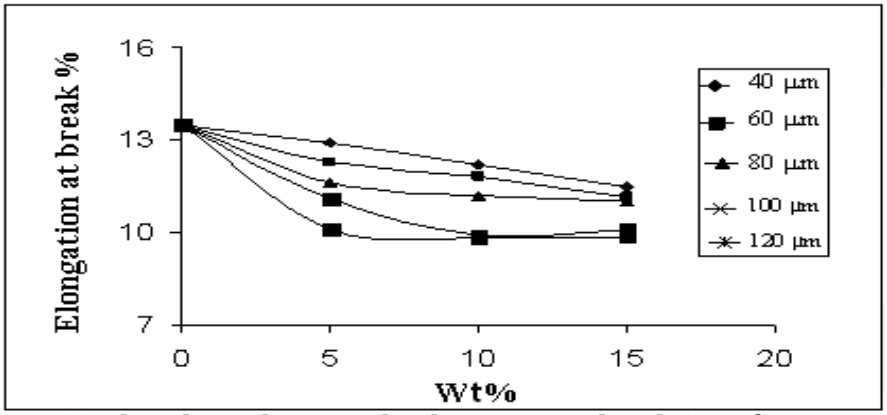

Figure (3) The relation between the elongations at break (%) of P/PMMA and weight percent of kaolin filler

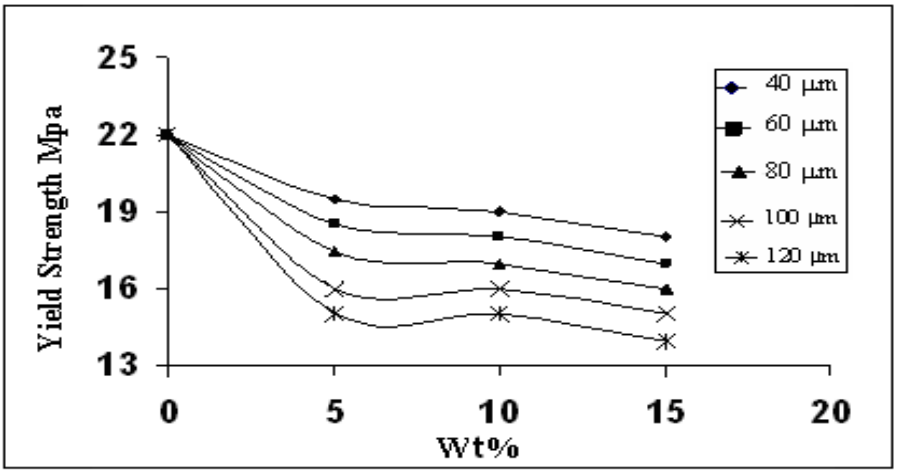

Figure (4) The relation between the yield strength of PP/PMMA and weight percent of kaolin filler percent of kaolin filler

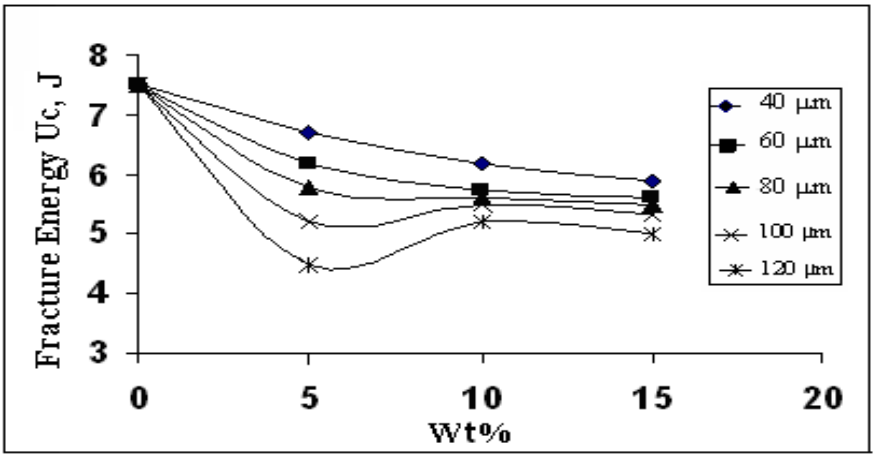

Figure (5) The relation between the fracture energy of PP/PMMA sample and weight percent of filler in different particle sizes

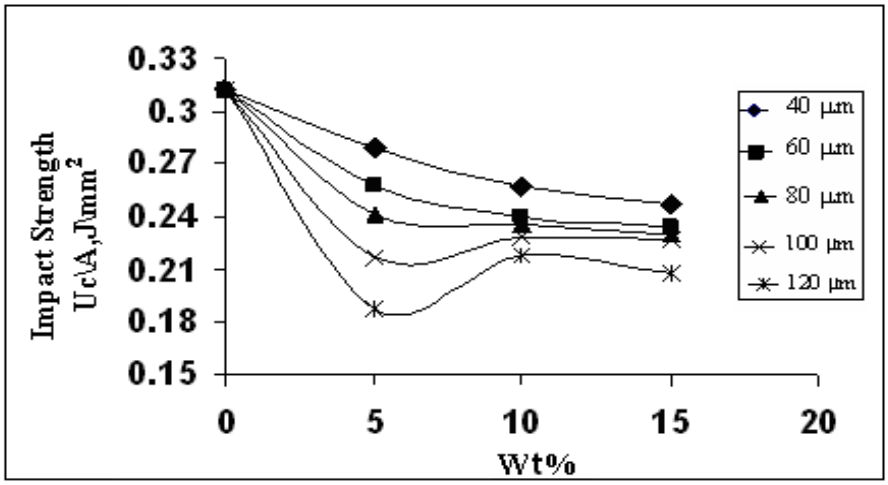

Figure (6) The relation between the impact strength of PP/PMMA sample and weight percent of kaolin filler in different particle sizes

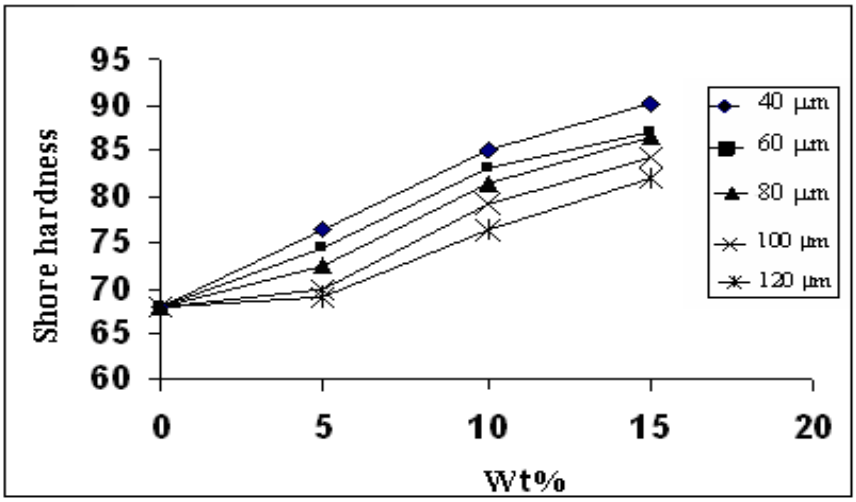

Figure (7) The relation between the shore hardness of PP/PMMA sample and weight percent of kaolin filler in different particle sizes

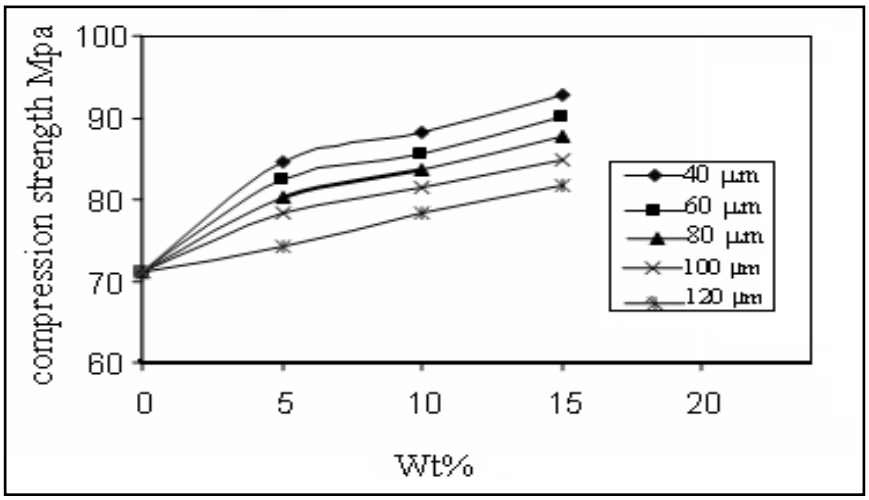

Figure (8) The relation between the compression strength of PP/PMMA sample and weight fraction of kaolin filler in different particle sizes

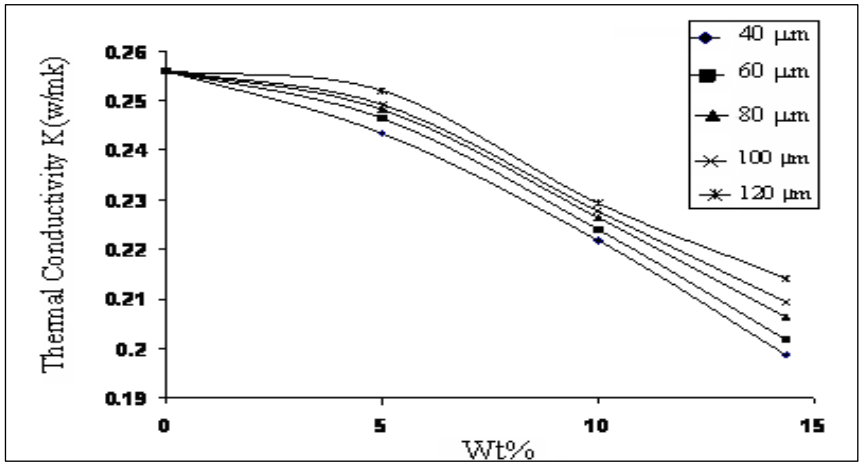

Figure (9) The relation between the coefficients of thermal conductivity of PP/PMMA sample and weight percent of kaolin filler in different particle sizes

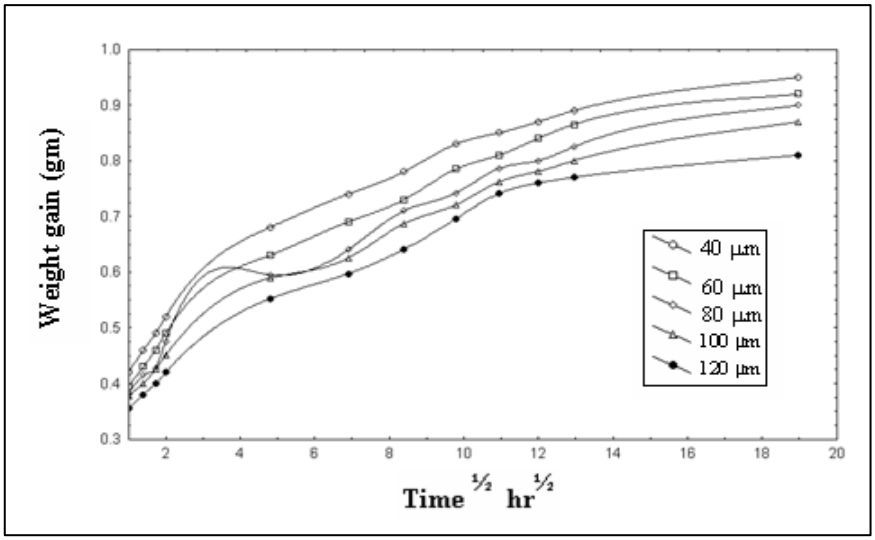

Figure (10) The relation between the weight gains of PP/PMMA/kaolin (72/18/10) % and the square root of time

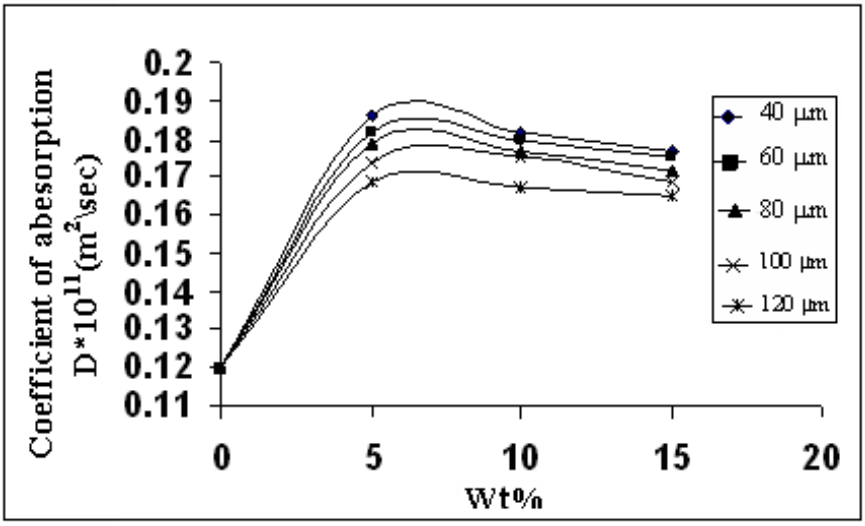

Figure (11) The relation between the coefficients of diffusion and weight percent of kaolin filler

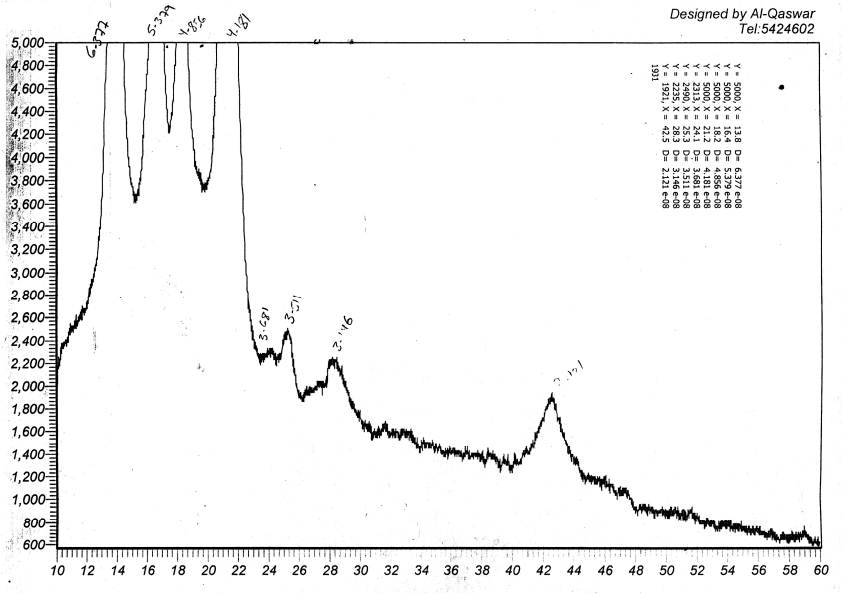

Figure (12) X-ray diffraction pattern of PP/PMMA kaolin (80/20)

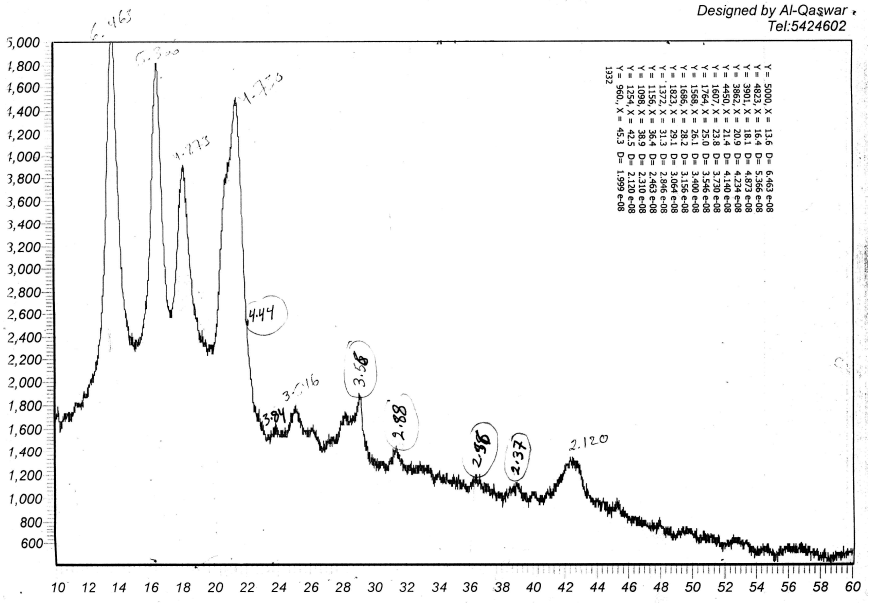

Figure (13) X-ray diffraction pattern of PP/PMMA/kaolin (76/19/5) %

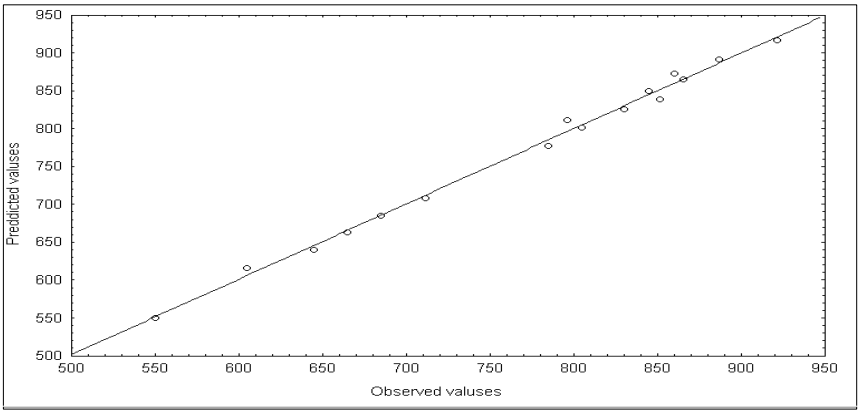

Figure (14) Experimental versus predicted values for Eq. (1)

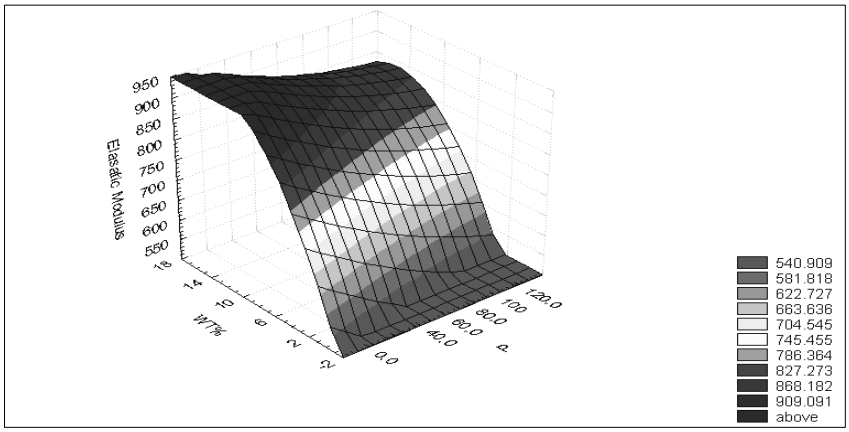

Figure (15) Three dimensional representation of Eq. (1) describing the variation in modulus of elasticity with weight fraction percent of filler content kaolin filler and the particle size for PP/PMMA/kaolin

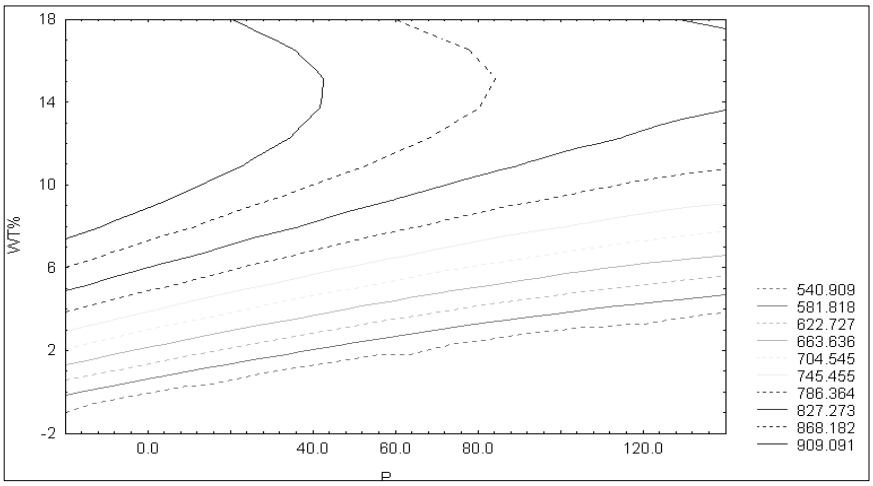

Figure (16) Contour plot obtained from the three dimensional plot Figs. (15)