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Improvement of thermal conductivity and mechanical properties of cold curing acrylic material

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ABSTRACT: This study was designed to improve the thermal conductivity of cold curing PMMA acrylic denture base material at different thickness 2, 3 and 4mm and by adding alumina powder Al_2O_3 and investigate the effect of this additive on some mechanical-physical (hardness, compression and impact) properties. Alumina powder was added to PMMA powder in percentage 4%. 60 specimens were constructed and divided into two groups according to the tests. The thermal conductivity of the samples had been measured using Lee-disk; while the compressive resistivity had been found using Universal machine. Whereas the hardness test was done using the Charpy's pendulum impact machine. The results show that after the reinforcement with weight 4% percentage of Alumina powder, mechanical properties (hardness and compression) increased while the impact decreased. The results have shown also that the increase in coefficient of thermal conductivity occurred with the addition of Al_2O_3 powder.

INTRODUCTION

Thermal conductivity is a measure of the ease with which temperature is transmitted through a material and is a basic material property. Materials with high thermal conductivity are called conductors and those with low conductivity are called insulators. Solid conductors (such as metals) typically have thermal conductivities in the range of 10 to 428 W/°K. m while insulators (such as polymers, glasses and ceramics) have values in the range of 0.1 to 2 W/°K m. Furthermore, thermal conductivity changes as a weak function of temperature and rarely changes by a factor of ten within a general class of materials. Determination of a material's thermal conductivity is important in evaluating its utility for specific applications The higher thermal conductivity of the filler cannot be taken into advantage and the composite behaves like a hollow material, thus reducing its conductivity compared to the dense reference matrix (1, 2).

The polymethylmethacrylate PMMA is the most reliable material for the construction of complete and partial dentures, but it is lacking an important property which is its thermal conductivity, where thermal conductivity plays an important role in patient satisfaction with complete and partial dentures. The suitability of any material for structural applications may be determined by mechanical tests. Such testing includes a determination of the ability of a material to withstand various stress systems which may be tensile, compressive, shear or cyclic in nature. The behavior of any material is also influenced by the presence of defects, the intrinsic micro structural features and the rate of application of stress, which may vary from exceedingly slow rates of deformation to impact loading. Aluminum has been acquiring increasing significance for the past few decades due to its excellent properties and diversified range of applications (5, 6, 7).

PMMA also has low thermal conductivity approximately 0.21 W/m.°K (3,4,8) compared with gold or cobalt alloy denture base materials and this can present problems during denture processing as the heat produced cannot escape, leading to a temperature rise and this may lead to porosity during fabrication (9) . From the patient's point of view, the problem with low thermal conductivity is that in edentulous patients wearing full dentures, the palate is partially covered by the denture base; consequently, the ability to sense transient temperature change at the palate may be affected by the thermal characteristics of the denture base material. Studies have shown that physical characteristics of denture base materials may affect patient acceptance of denture prostheses by altering sensory experience of food during mastication (10). Also thermal characteristics of denture base can became important factors affecting the gustatory response. Several attempts have been carried out to improve thermal properties of acrylic such as addition of filler like (Tin, Aluminum, Copper) or addition of whisker to the matrix of acrylic resin. Thermal conductivity improved but some other properties may be affected adversely like esthetic, tensile and impact strength (11).The suitability of any material for structural applications may be determined by mechanical tests. Such testing includes a determination of the ability of a material to withstand various stress systems which may be tensile, compressive, shear or cyclic in nature. The behavior of any material is also influenced by the presence of defects the intrinsic micro structural features and the rate of application of stress, which may vary from exceedingly slow rates of deformation to impact loading(12) .

In the present study alumina has been added to cold cure acrylic resin to evaluate the effect of this addition on thermal conductivity at different thickness and some other physical and mechanical properties. Alumina was selected because it has high thermal conductivity and it's a well-known biocompatible material, also it is white powder that will not affect esthetic severely (9).

MATERIALS AND METHODS

The present study was done in experimental laboratory study and the material was: cold curing acrylic resin (RESPAL-NF liquid- Pro Base cold powder). 60 specimens were prepared from cold-cure acrylic resin and were mixed depending on the method of processing according to manufacturer's instruction 1:2 by volume (13). The samples were divided into six groups according to the test and each group was subdivided into two subgroups according to the percentage 4% of alumina added (17) and the difference in thickness of PMMA material. The required weight of the powder of the polymer and Al_2O_3 was weighted by using electronic balance for each group. Mixing of polymer and alumina powder was done by mortar and pestle until a homogenous color was attained within approximately 5 minutes.

Physical and Mechanical tests

A-Thermal conductivity test

Acrylic specimens with dimension 11.25 cm in diameter and 2, 3 and 4 mm in thickness were prepared. The thermal conductivity of acrylic specimens were studied by using thermal conductivity apparatus (Lee's disc).The average of five readings were calculated (Table 1).The standard cooling curve was drawn with time along X-axis and the temperature along the Y-axis (Figure 1). The rate of cooling dθ/dt (slope) of each test at θ_2 was determined from Figure 2. The radius r of the disc, the disc thickness d , the lower metallic disc mass m and the specific heat for the lower metallic disc s were recorded from catalog . The value of thermal conductivity K_L in W/m.°K of the various samples were found using the formula:

$$K_{L=} \quad m\ s\ d\ \text{slope} / 60\ A\ (\theta 2 - \theta_1) \qquad W/m.^oK$$

Where: $A = \pi r^2 = 99.04\times 10^{-4}\ m^2$ = Area of the disk
$s = 100$ cal / Kg .° K , $m = 1$ Kg
θ1 = Steady temperature of the disc = 98°c
θ2 = Steady temperature of the steam chamber in.
d = thickness of the sample (2 , 3 and 4)mm
dθ/dt = rate of cooling = slope

B- Hardness test

Specimens were prepared in the form of a cylindrical disk with diameter (11.25cm), (Amsler, KARL-KOLB/Germany) tester was used in this study for measuring the indentation hardness(Fig 3).All specimens were immersed in distilled water before tested (16) .The test load was set from(10 to 60 Kg) . The contact period between the specimen and the indenter was six seconds. After that the measurements were taken directly from the scale, five readings were done on different areas of each specimen and the average of five readings was calculated.

C- Impact Tests

This test aims at subjecting the denture to sudden load. Charpy's pendulum impact testing machine (ZEIZZ-West Germany) (Fig4) was used to determine the relative impact resistance of acrylic resin with and without alumina powder. The machine is a pendulum-type with a disc-shaped hammer carrying a knife edge. Rectangular specimens were prepared (40 mm long, 5 mm in both thickness and width), each having a 1 mm deep standard notch with 60° angle in the middle of the bar. All specimens were immersed in distilled water before tested, then the specimen was simply supported horizontally at both ends and not clamped and the impact strength means of a specimen was recorded in kg .m of energy absorbed in breaking the specimen.

D-Compressive Strength Test:

Specimens for this test were in the form of a cylindrical with dimensions (20mm × 10 mm) were subjected to compressive load until failure, using a universal testing machine. All specimens were immersed in distilled water before tested. Each specimen was placed between two parallel flat surfaces and the compressive load was gradually increased until sample failure occurred. A great care was required to insure proper transfer of load from testing machine to specimen. The load was made axially and applied uniformly over the end of the specimen. The compressive strength means calculated resin with and without alumina powder in N/mm^2 from the following equation:

Compressive Strength = F/A
F: Force at failure (Newton)
A: Minimum cross sectional area (mm^2)

RESULTS AND DISCUSSION

The mean values of thermal conductivity were presented in (Table 2) and The variation of thermal conductivity of the cold-cure acrylic resin samples with thickness shown in (Fig 5).The results have shown that after the reinforcement with weight 4% percentage of alumina powder reduction occurred with the increase in thickness while the result of thermal conductivity test appeared that the addition of alumina powder increase the value of thermal conductivity. The use of thermal conductive particles within the PMMA matrix increased the thermal conductivity; this might be due to the overlapping of the particles inside the matrix to bridge the insulating effect of the PMMA matrix (14). The addition of thermal conductive particle to PMMA matrix can increase the thermal conductivity of the isolating material. The mechanical properties of all groups test at room temperatures are shown in (Table 3). The results have shown that after the reinforcement with weight 4% percentage of alumina powder, the value of hardness and compression were increased .This increasing may be attributed to the randomly distributed particles of a hard material (alumina) into acrylic matrix. From the results of impact strength test it was shown that the addition of Al_2O_3 powder lowered the value of impact strength. The decrease of impact strength is comparable with the amount of Al_2O_3 powder added. This reduction in impact strength may be due to stress concentration around Al_2O_3 hard particles. The presence of another reason is the weak bond between Al_2O_3 particles and PMMA matrix which make the filled resin possess lower impact strength. This reduction in impact strength may be due to stress concentration around Al2O3 hard particles which lead to crack propagation also another reason could be weak bond between Al2O3 particles and PMMA matrix make the filled resin possess lower impact strength. When they added alumina whisker form to PMMA. The study agrees with the result obtained by Abdul Ameer (15).

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Table (1): Time – Temperature record during cooling of one group test

Time t(min)	Temperature at thickness (3mm) θ(^{0}C)	Temperature at thickness (3mm) +4%Alumina θ(^{0}C)
0	92	91.5
1	88.8	87.8
2	85.5	84
3	83	79.5
4	80.6	76.2
5	78.5	73
6	76.4	69.6
7	74.8	68.3
8	72.7	67
9	71.8	65.2
10	69	64
11	66.7	62.2
12	62	60
13	60	
14		
	θ_2= 82^{o}c	θ_2= 81^{o}c

Table (2): The mean of thermal conductivities K_L at different thickness of all groups test

thickness(mm)	Thermal conductivity K_L(W/m.^{o}K)	Thermal conductivity K_L+ 4% Al_2O_3 powder (W/m.^{o}K)
2	0.19	0.26
3	0.18	0.24
4	0.14	0.21

Table (3): The mean of mechanical properties of all groups test at room temperatures

	Hardness Test HRR	Compression Test N/mm^2	mpact Test Kg.m
Without powder	112	305	75.6
With powder	114	312	72.7

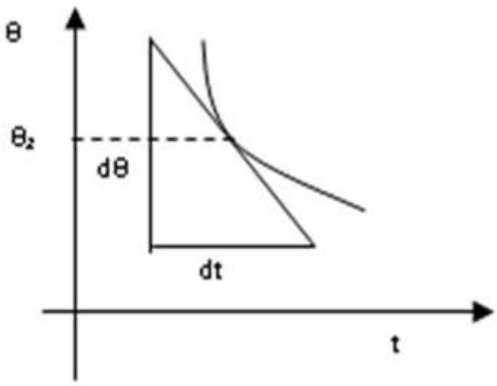

Figure (1): The Standard Cooling Curve

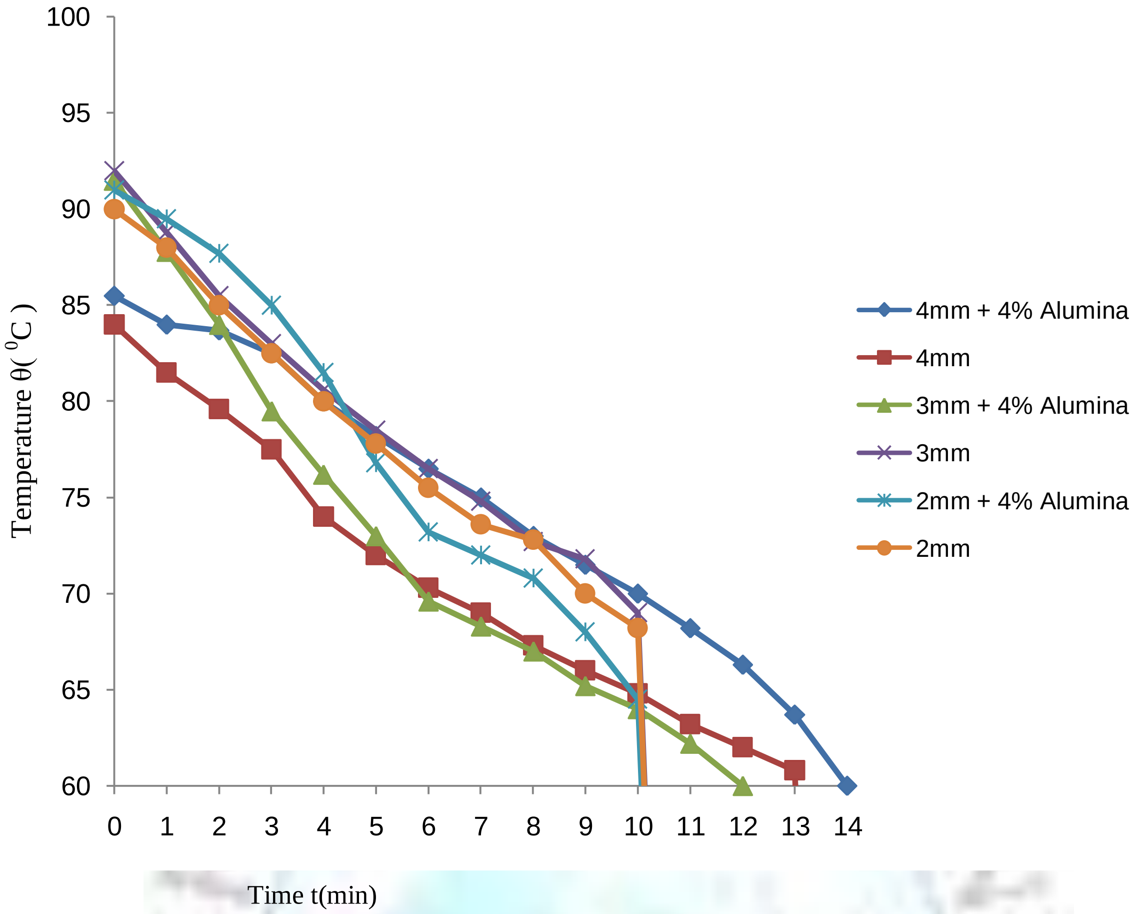

Figure (2): The cooling curve of each test

Fig (3): (Amsler, KARL-KOLB/Germany) machine for measuring the indentation hardness

Fig (4): Charpy's pendulum impact testing machine

(ZEIZZ-West Germany)

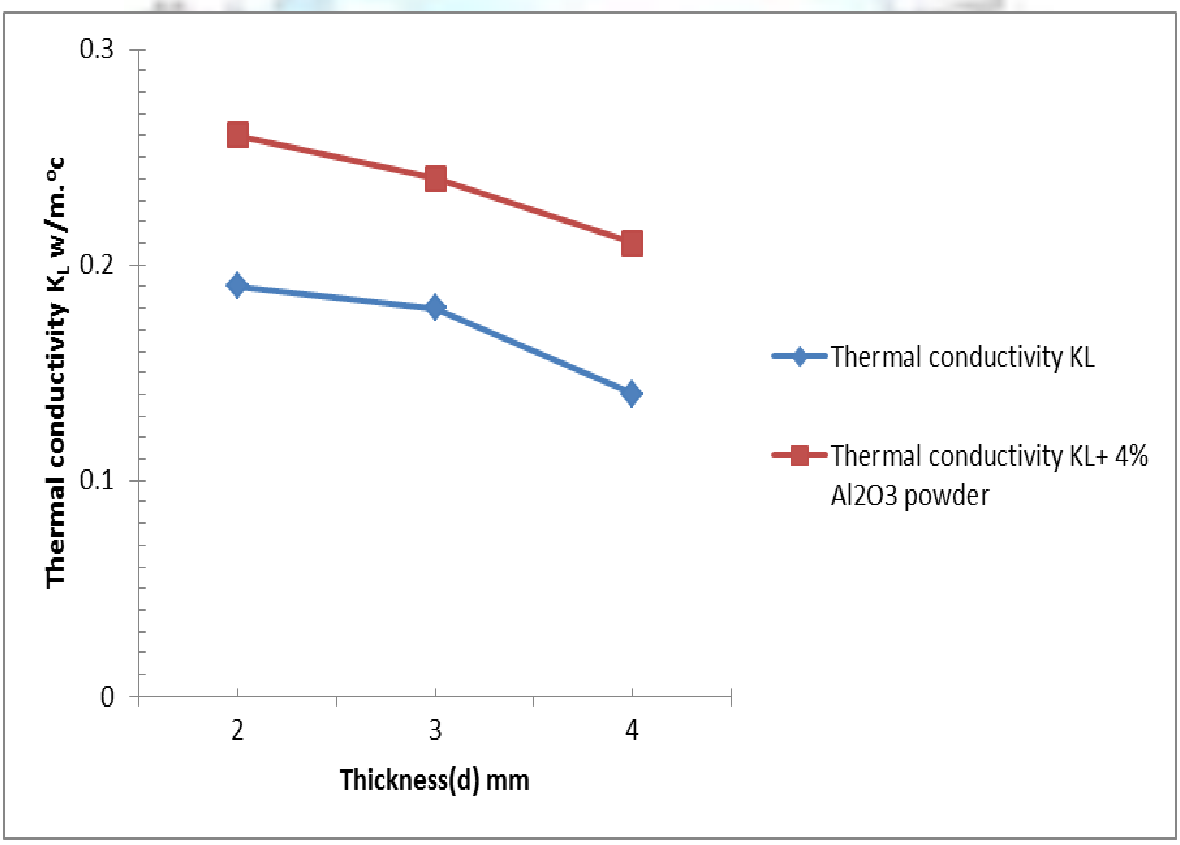

Fig (5): The variation of thermal conductivity of the cold-cure acrylic resin samples with thickness