Measuring thermal conductivity of different prosthetics socket lamination

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Abstract

Within the prosthesis, the residual limb is often subjected to a hot and moist environment which is both uncomfortable that may contribute to skin irritation, blistering, and and reduces life of the prosthetic limb, so that to maintain a healthy, clean and comfortable residual limb, the socket must have the ability to keep the limb cool. In present study is design of a system for measuring the thermal conductivity of different lamination materials of prosthetic socket which manufactured in Baghdad center using perlon, fiberglass and acrylic resin. The experimental results show that the thermal conductivity ranged from (**0.1289-0.22982**) for socket materials. Also the results demonstrate increasing perlon layers with constant fiberglass layers the thermal conductivity increased by (46%),at the same time the result shows that with increasing perlon layers with absence fiberglass layers the thermal conductivity Decrease by (67.9%).also it was found that increasing fiberglass layers from zero to two layers with fixing perlon layers leaded to increased in thermal conductivity by(78.27%,41.89%,16.2%) for twelve, ten and eight layers of perlon respectively.

Keywords: socket materials, perlon, fiberglass, thermal conductivity, lee‘s disk method.

قياس التوصيل الحراري لنماذج مختلفة من الوقب البديل

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الخلاصة

مع استخدام الطرف البديل دائما ما يتعرض العضو المتبقي الى بيئة حارة ورطبة وهذا بالطبع غير مريح و يساهم في تهيج الجلد و ظهور تقرحات وانخفاض في عمر الطرف الصناعي.ومن اجل الحفاظ على العضو المتبقي صحيا ونظيفا ومريحا يجب ان يحافظ الطرف البديل على الطرف المتبقي باردا.في هذه الدراسة تم تصميم جهاز لقياس التوصيل الحراري لنماذج مختلفة من مادة الوقب البديل التي تم تصنيعها في مركز بغداد باستخدام طبقات من (perlon)و(fiberglass)و(acrylic resin).بينت النتائج العملية ان التوصيل الحراري لجميع النماذج ما بين (**0.22982-0.1289**)0كذلك بينت النتائج انة بزيادة عدد طبقات (perlon) مع ثبات طبقات (fiberglass) فان التوصيل الحراري (K) يزداد بنسبة (46%) بنفس الوقت بزيادة عدد طبقات (perlon) مع غياب طبقات (fiberglass) فان التوصيل الحراري (K)يقل بنسبة (67.9%). كما وجد أن زيادة طبقات (fiberglass) من صفر إلى طبقتين مع ثبات طبقات perlon يؤدي إلى زيادة في التوصيل الحراري بنسبة (78،27٪- 41،89٪- 16.2٪) لكل من اثني عشر, عشرة وثماني طبقات من perlon على التوالي.

1. Introduction

Amputee is the person who loses a part of one of the parties of his body or may be removed party fully or group of Parties of the body [1].The lower limb which is classified to be amputated above the knee or amputation below the knee [2]. After the patient's exposure to the amputation begins great suffering for the patient how to compensate for this part is very important, which lost, of course, one of the most important of these solutions is the manufacture of artificial limb replacement. Artificial limb for amputation consists of four basic parts are respectively the foot, pylon, coupling and prosthesis socket [3]. The insulated environment of the lower-limb prosthesis can result in elevated residual-limb skin temperatures that may contribute to skin irritation, blistering, and a reduced quality of life [4]. Heat exchange between the human thermal system and the environment continuously take place at the skin surface .Heat production continuously occurs inside the body various biochemical action and increase with exercise. Heat generated inside the body is transferred by convection to the skin surface through the blood flow and by conduction in the radial direction. Cooling of human body occurs by several mechanisms which are including convection, radiation, evaporation and conduction [5]. A prosthetic socket is an insulated environment that limits these mechanisms. Trapping heat and perspiration ,which lead to an increase in the occurrence of skin injuries so that within the prosthesis the residual limb is often subjected to a hot and moist environment which is both uncomfortable and potentially harmful[6].

2. Experimental procedures

2.1 Materials Used in Socket

The material selection for prosthetic devices is important because the material directly affects the comfort of the socket and the level of mobility for the patient. The materials of the socket chosen were randomly laminated this means that the material is isotropic [7], [8].

2.2 Manufacturing socket lamination

To measure the thermal conductivity, Specimens were prepared the method of preparation of different specimens is called "vacuum method" which prevents cavities and defects [9]

4. Thermal conductivity measurement

Prostheses can be uncomfortable to the wearer due to the entrapment of heat and sweat within the socket. To maintain a healthy, clean, and comfortable residual limb, the socket must have the ability to keep the limb cool [10]. The thermal conductivity of prosthesis socket may have significant effects on skin temperature so that will design a system according to "Lee‘s disc method" to determine the thermal conductivity of different materials were used in socket lamination [11]. A system used to evaluate the thermal conductivity of a prosthetic material would be useful in determining materials are more suitable to keep the residual limb cooler.

4.2 Lee‘s disc method

The apparatus used was a modification of the standard Lee’s disk method type (Griffin and Gearge) for the measurement of thermal conductivity by the absolute plane parallel plate technique [11] this method consist of three identical copper disc (A, B and C) of 4 cm in diameter and 40 mm thickness inside each disc drilled hole from edge of the disc to it‘s center to accept thermocouples. Before the discs were assembled they are vanished to give them the same emissive and coated it with thermal jelly to facilitate good thermal contact. Electrical heater was manufactured locally used copper disc with (40,6)mm diameter and thickness respectively, the copper disc was grooved from one face with 3.6mm diameter, electrical heater wire with (90,1)mm length and diameter respectively and 150 ohm of resistance fit on the electrical insulator to prevent electrical short in circle form, enclose it in the groove of copper disc after sandwiched it by electrical insulator, then cover the groove by circle copper plate to prevent damage in electrical heater. After completed manufactured heater sandwiched it in between disc B and C and the specimen was then placed between copper disc A and B, tightening the clamp screw to hold the entire disc together. The whole assembly was placed in an enclosure to minimize the effect of environment temperature .A thermal insulation was placed in both side of disc (A,C) to minimize heat loss, a six thermocouples(type K) was used to measure temperature of disc (A, B, C), temperature of insulation and temperature of environment in the enclosure. Multi meter reader type
(victor 70 C) was used to read temperature of six thermocouple and selectors to transfer from one thermocouple to another in order to read it‘s temperature. When the power from a variable DC supply was switch on the temperature of disc (C,B) more than disc A, because of the presence of specimen that act as an isolator. The temperature was recorded every (10 minute) until reach to the equilibrium temperature of all discs at this time temperature is recording in addition to the sex thermocouples readings, the current and voltage applied to heater was monitored. When temperature of all parts of the apparatus has been stable to within $\pm 0.1\ ^{\circ}C$ for 20 minute The thermal conductivity (k) of the specimen at thickness (d) and radius (r) was calculated using equation (11) derived in theory section.

4.3 Calibration of device

To validate the apparatus, materials with known thermal conductivities will be tested(wood, Jepson, cement) in two trails the mean thermal conductivity calculated will be compared to the know thermal conductivity to establish the accuracy of the apparatus the system will be considered accurate if the calculated mean thermal conductivity is within ten percent of the established values [10].

5. Theory

Modified Lee's disc method which used in present study has determined the thermal conductivity of small thin disc of material the arrangement is shown in Fig. (2.1). from the energy balance for the apparatus

$$Q_{input} = Q_{output}$$

$$Q_{\substack{input\ to \\ heater\ element}} = Q_{\substack{output\ from \\ disc}} \quad (C,H,B,S,A) \qquad (1)$$

$$Q_{input} = I.V \qquad (2)$$

$$Q_{output,C} = 2\pi r d_c T_c e + k_{ins}\pi r^2 \left(\frac{T_c - T_{ins,c}}{X_{ins\,1}}\right) \qquad (3)$$

$$Q_{output,H} = 2\pi r d_H \left(\frac{T_c + T_B}{2}\right) e \qquad (4)$$

$$Q_{output,B} = 2\pi r d_B T_B\, e \qquad (5)$$

$$Q_{output,S} = 2\pi r d_s \left(\frac{T_B + T_A}{2}\right) e \qquad (6)$$

$$Q_{output,A} = 2\pi r d_A T_A e + k_{ins}\pi r^2 \left(\frac{T_A - T_{ins,A}}{X_{ins\,2}}\right) \qquad (7)$$

Sub Equ. (2-7) in Equ 1

$$I.V = 2\pi r d_c T_c\, e + k_{ins}\pi r^2\left(\frac{T_c - T_{ins,c}}{X_{ins\ 1}}\right) + 2\pi r d_H\left(\frac{T_c + T_B}{2}\right)e + 2\pi r d_B T_B\, e + 2\pi r d_s\left(\frac{T_B + T_A}{2}\right)e + 2\pi r d_A T_A e + k_{ins}\pi r^2\left(\frac{T_A - T_{ins,A}}{X_{ins\ 2}}\right)$$

$$I.V = e\ 2\pi r\left[d_c T_c + d_H\left(\frac{T_c + T_B}{2}\right) + d_B T_B + d_s\left(\frac{T_B + T_A}{2}\right) + d_A T_A\right] + k_{ins}\pi r^2\left[\frac{T_c - T_{ins,c}}{X_{ins\ 1}} + \frac{T_A - T_{ins,A}}{X_{ins\ 2}}\right]$$

Where

$$X_{ins\ 1} = X_{ins\ 2} = X_{ins}$$

$$e = \frac{I.V - k_{ins}\pi\, r^2\left[\frac{T_C + T_A - T_{ins,A} - T_{ins,c}}{X_{ins}}\right]}{2\pi r\left[d_c T_c + d_H\left(\frac{T_c + T_B}{2}\right) + d_B T_B + d_s\left(\frac{T_B + T_A}{2}\right) + d_A T_A\right]}$$

From the standard equation for conduction of heat through an object, the heat flowing through the specimen S is

$$Q_{sample} = k_S\, \pi\, r^2\, \frac{T_B - T_A}{d_s} \qquad (9)$$

All heat entering (S) from (B) is that which is emitted by (S) and (A) together [10]

$$Q_{B\ S} = 2\pi r d_s\left(\frac{T_A + T_B}{2}\right)e + 2\pi r d_A T_A\, e + k_{ins}\pi r^2\,\frac{T_A - T_{ins,A}}{X_{ins}} \qquad (10)$$

Thus from equation(9)and(10)

$$k_S\,\frac{T_B - T_A}{d_s}\,\pi r^2 = 2\pi r d_s\left(\frac{T_A + T_B}{2}\right)e + 2\pi r d_A T_A\, e + k_{ins}\pi r^2\,\frac{T_A - T_{ins,A}}{X_{ins}}$$

Then, the thermal conductivity of sample given below

$$k_S = \frac{d_s\, e}{(T_B - T_A)}\left[d_s\left(\frac{T_A + T_B}{r}\right) + \frac{2d_A T_A}{r} + \frac{k_{ins}}{e}\frac{(T_A - T_{ins,A})}{X_{ins}}\right]$$

6. Result

14 specimens were tested using "lee‘s disc method" which manufactured for this goal. the thermal conductivity of each sample can calculated and by taking the average value of thermal conductivity (K) ,the thermal conductivity for all lamination can found as shown in table (2)

The effects of increasing perlon layers with constant layers of fiber glass on thermal conductivity were showing in fig(1) while The effects of removing fiber glass layers from lamination lay up on thermal conductivity were showing in fig(2)

Also the effects of increasing fiber glass layers with fixing layers of perlon on thermal conductivity were showing in fig (3)

7. Discuss

Fig (1) show that with constant two fiber glass layers in the lamination lay up the thermal conductivity (K) is increasing slowly with the increasing of perlon layers, by compared the lamination of six perlon layers with eight, ten and twelve perlon layers in the lamination the thermal conductivity increased with (22.2%, 41% and 46%) respectively. which lead to increase in the lamination thickness of sample, in spite of the increase in the lamination thickness decrease the thermal conductivity of lamination according to Fourier series law in heat conduction .but the change in the thickness very small can be neglected. Fig (2) shows that with absences fiber glass layers in the lamination the thermal conductivity (K) is decreased with increasing the perlon layers in the lamination layup, by compared the lamination of six perlon layers with eight, ten and twelve perlon layers in the lamination the thermal conductivity decrease with (31.2%,38.9%and67.9%) respectively. fig(3) shows that with only one fiber glass layer in the lamination the thermal conductivity (K) is increased very little with increasing the perlon layers in the lamination layup by compared the lamination of six perlon layers with eight perlon layers in the lamination the thermal conductivity increased with (1.27%). Fig (4) shows that with six layers of perlon in the lamination the thermal conductivity (K) is decreased with increasing the fiber glass layers in the lamination layup by compared the lamination of zero fiberglass layers with one and two fiber glass layers with six perlon layers in all the lamination the thermal conductivity decrease with (16.1% and 38.1%) respectively.

Fig(5) shows that with fixed eight layers of perlon in the lamination the thermal conductivity (K) is increasing with increasing the fiber glass layers in the lamination layup by compared the lamination of zero fiberglass layers with one and two fiberglass layers in the lamination the thermal conductivity increased with (14.4% and 16.2%) respectively. Fig (6) shows that with twelve layers of perlon in the lamination the thermal conductivity (K) is increasing with increasing the fiber glass layers in the lamination layup by compared the lamination of zero fiberglass layers two fiberglass layers in the lamination the thermal conductivity increased with (78.2%). Finally table (2) show that lamination numbers (2,4,10,11) having better thermal conductivity compared with lamination numbers (8,9,5,7) in spite of both having the same numbers of layers(the same numbers of perlon and fiber glass layers),by comparing the thermal conductivity of lamination (2 with 3),(4 with 9),(10with 5) and(11 with7) the thermal conductivity increased by(14.5%, 22.9% , 5.2% and 45.7%)also it was found that increasing fiberglass layers from zero to two layers with fixing perlon layers leaded to increased in thermal conductivity by (78.27%,41.89% and16.2%) for twelve, ten and eight layers of perlon respectively. the reason for this difference is related to the method of sandwich lamination of the first group .the layer of the perlon are distributed equally on each side of the central fiber glass layers. Also in Iraq during summer season the temperature of environment very hot reached 50 c and the temperature transfer from high rejoin to low rejoin, so that the temperature will transfer from environment to residual limb amputee which causes rise the temperature of residual limb therefore in this condition need a prosthetic socket with low thermal conductivity to can keep it‘s temperature. From this it can be noticed that lamination which consist of two layers of perlon plus two layers of fiber glass plus two layers of perlon binding by acrylic resin matrix may be considered the optimum lamination layup comparing with lamination used in Baghdad center for prosthetic and orthotic which consists of five layers of perlon plus two layers of fiber glass plus five layers of perlon binding by acrylic resin matrix in spite of reducing in numbers of layers the thermal conductivity decreasing by (75.6%).

8. Conclusion

We measured thermal conductivity for 14 lamination sample by device design essentially for this goal the results show that:

1-with constant two fiber glass layers in the lamination lay up the thermal conductivity (K) is increasing slowly with the increasing of perlon layers, by compared the lamination of six perlon layers with eight, ten and twelve perlon layers in the lamination the thermal conductivity increased with (22.2%, 41% and 46%) respectively

2-with absences fiber glass layers in the lamination the thermal conductivity (K) is decreased with increasing the perlon layers in the lamination layup, by compared the lamination of six perlon layers with eight, ten and twelve perlon layers in the lamination the thermal conductivity decrease with (31.2%,38.9%and67.9%) respectively.

3- lamination numbers (2,4,10,11) having better thermal conductivity compared with lamination numbers (8,9,5,7) in spite of both having the same numbers of layers(the same numbers of perlon and fiber glass layers),by comparing the thermal conductivity of lamination (2 with 3),(4 with 9),(10with 5) and(11 with7) the thermal conductivity increased by(14.5%, 22.9% , 5.2% and 45.7 %).

4- lamination which consist of two layers of perlon plus two layers of fiber glass plus two layers of perlon binding by acrylic resin matrix may be considered the optimum lamination layup comparing with lamination used in Baghdad center for prosthetic and orthotic which consists of five layers of perlon plus two layers of fiber glass plus five layers of perlon binding by acrylic resin matrix in spite of reducing in numbers of layers the thermal conductivity decreasing by (75.6%).

5- lamination (222) which are consist of have the best K , during which k is decrease with 75.6% comparison with the standard lamination (525).

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No. of lamination	Lay up	No. of layers	Description layers
1	626	14	(6Perlon+2fiber glass+6perlon)
2	525	12	(5Perlon+2fiber glass+5perlon)
3	624	14	(6Perlon+2fiber glass+4perlon)
4	424	10	(4Perlon+2fiber glass+4perlon)
5	323	8	(3Perlon+2fiber glass+3perlon)
6	422	8	(4Perlon+2fiber glass+2perlon)
7	222	6	(2Perlon+2fiber glass+2perlon)
8	606	12	(6Perlon+0fiber glass+6perlon)
9	505	10	(5Perlon+0fiber glass+5perlon)
10	404	8	(4Perlon+0fiber glass+4perlon)
11	303	6	(3Perlon+0fiber glass+3perlon)
12	414	9	(4Perlon+1fiber glass+4perlon)
13	313	7	(3Perlon+1fiber glass+3perlon)
14	412	7	(4Perlon+1fiber glass+2perlon)

Table (1) the lamination manufactured with different lay up[9]

No. of lamination	Lay up	Thermal conductivity K , (W/m. c)
1	626	0.22982
2	525	0.22111
3	624	0.1930568
4	424	0.19163
5	323	0.15674
6	422	0.15747
7	222	0.12891
8	606	0.12891
9	505	0.15583
10	404	0.1649
11	303	0.216488
12	414	0.18873
13	313	0.197451
14	412	0.18636

Table (2) thermal conductivity of each sample

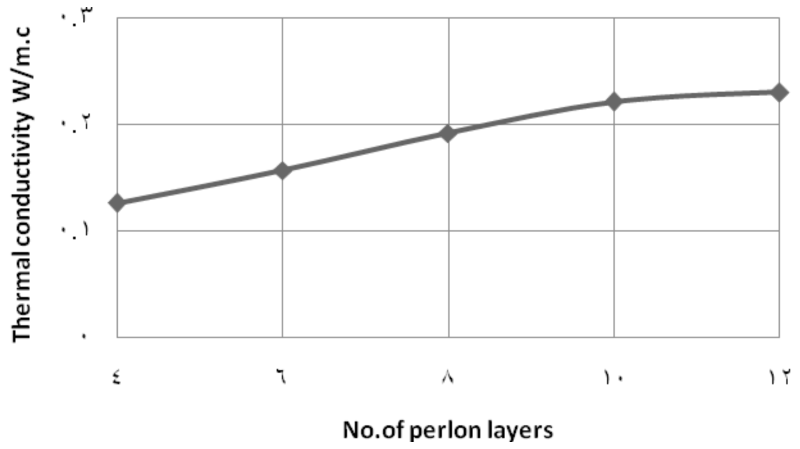


Fig (1) thermal conductivity against No. of perlon layers with two fiberglass layers

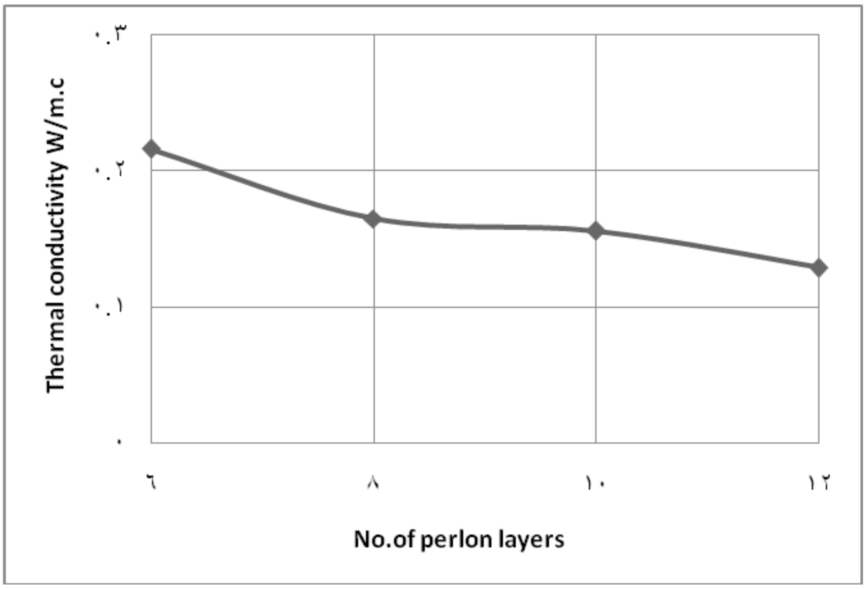


Fig (2) thermal conductivity against No. of perlon layers with absence fiber glass layers.

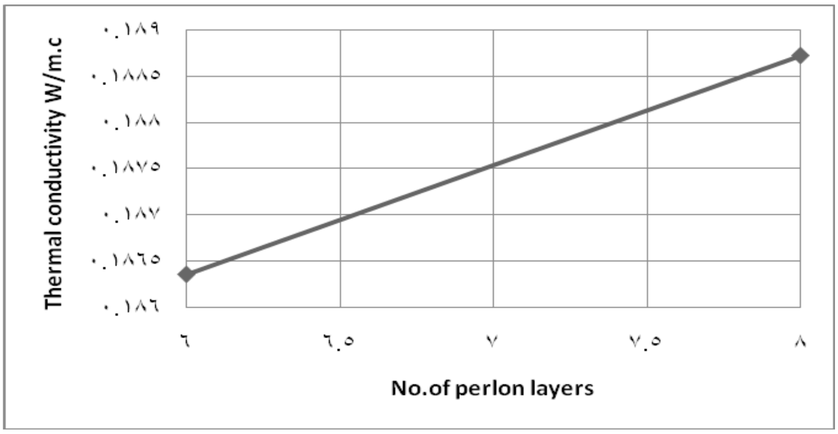


Fig (3) thermal conductivity against No. of perlon layers with one fiber glass layers.

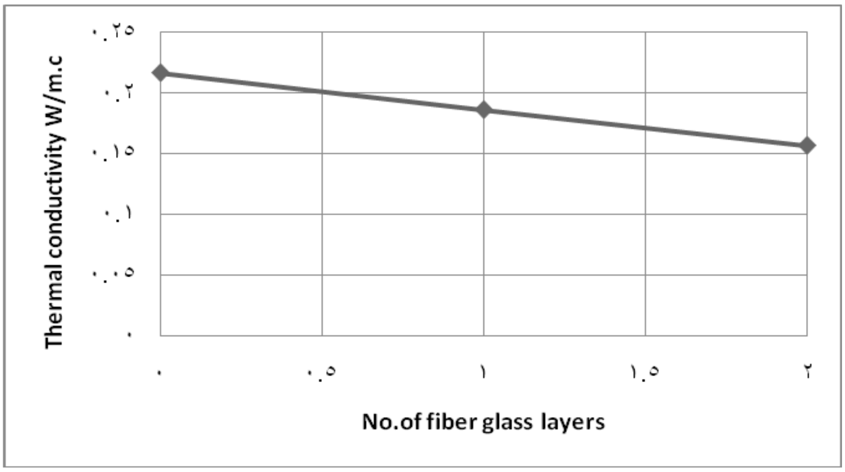


Fig (4) thermal conductivity against No. of fiber glass layers with six layers of perlon

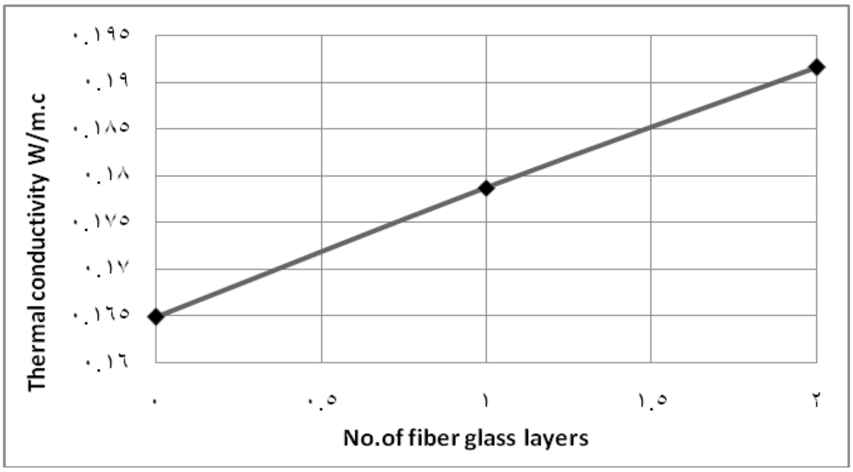


Fig (5) thermal conductivity against No. of fiber glass layers with eight layers of perlon

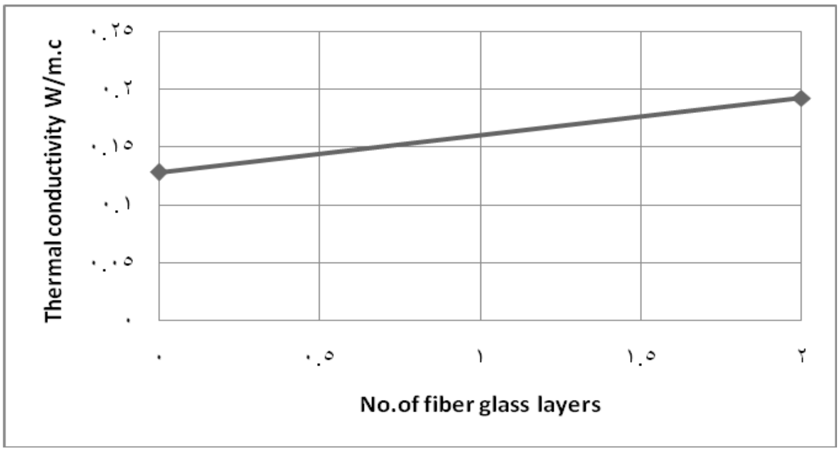


Fig (6) thermal conductivity against No. of fiber glass layers with twelve layers of perlon

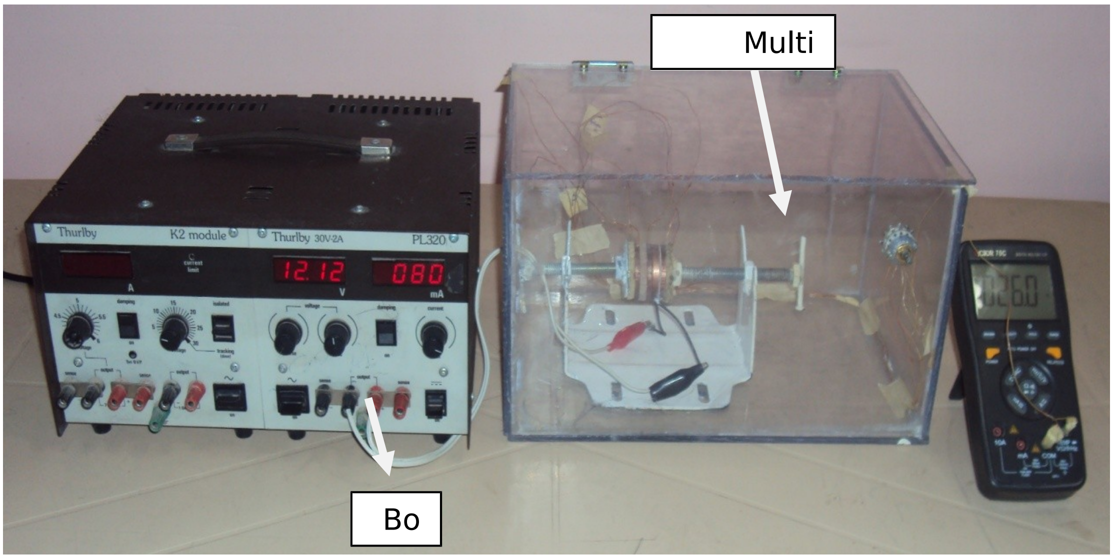
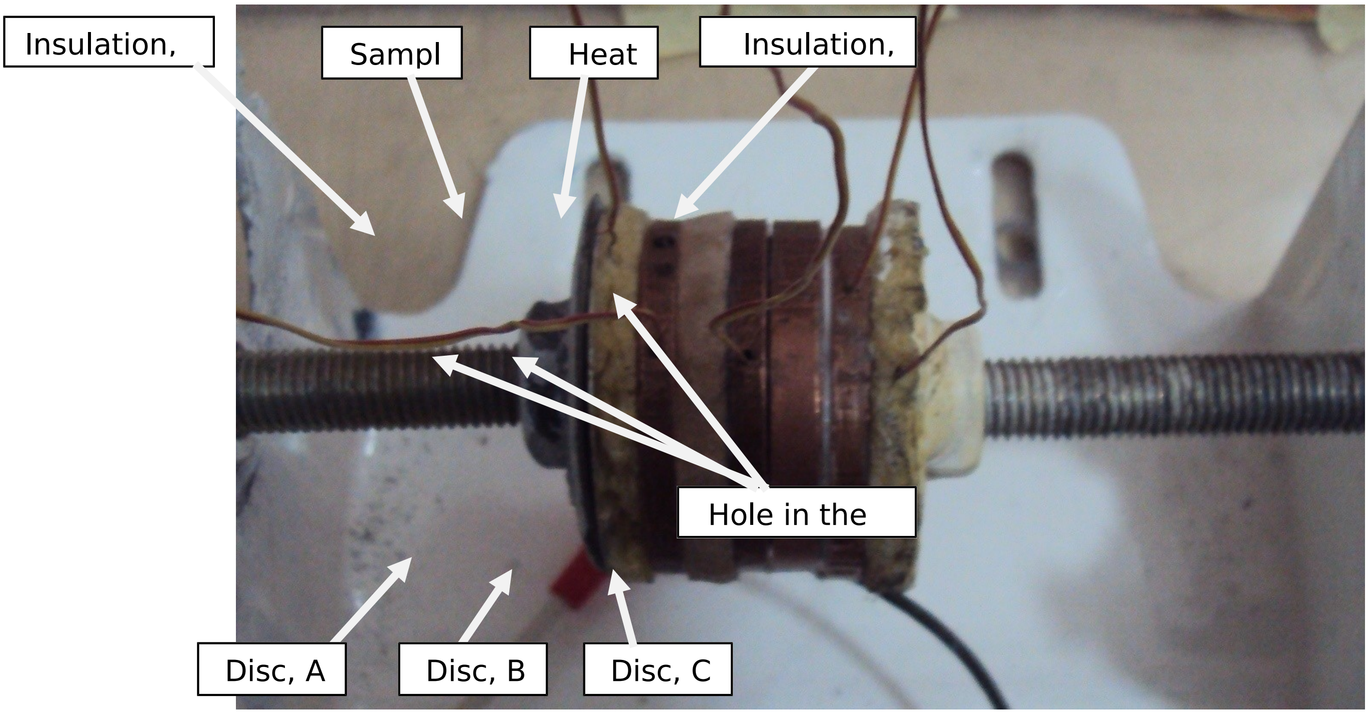


Fig (7) Lee's disc apparatus



Fig(8) arrangement of copper disk and position of sensors

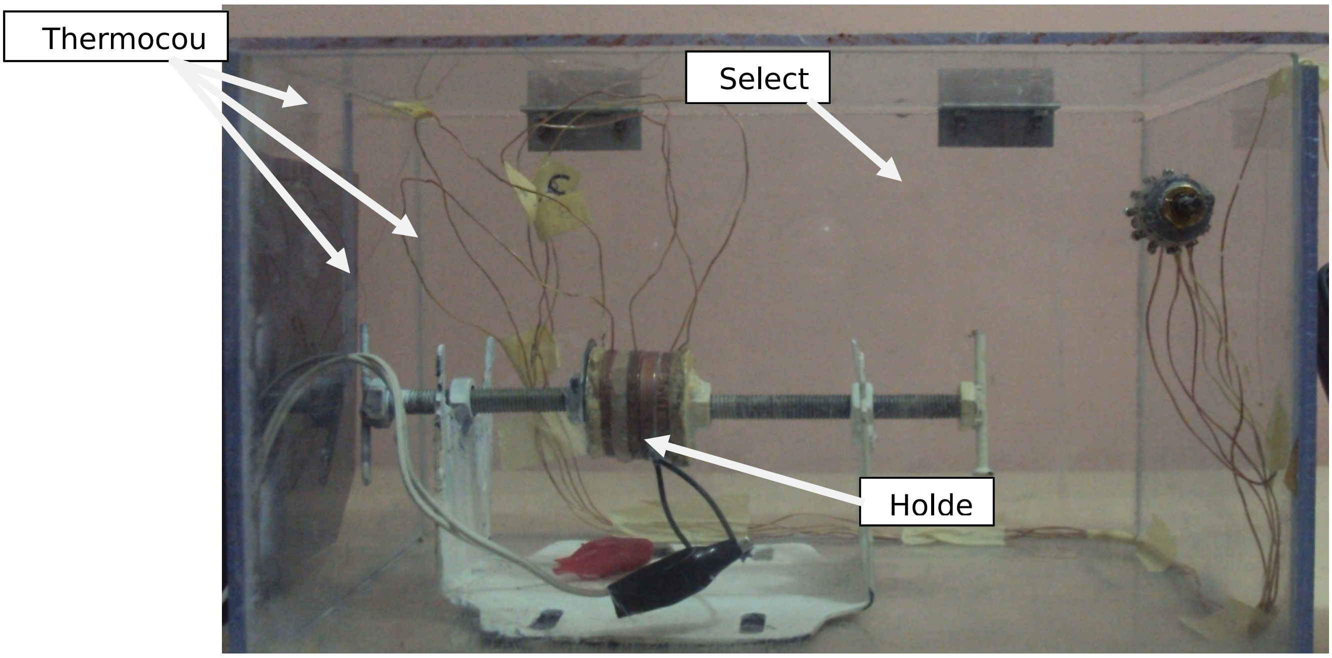


fig (9) box and selector

Fig (10) different material of lamination layup

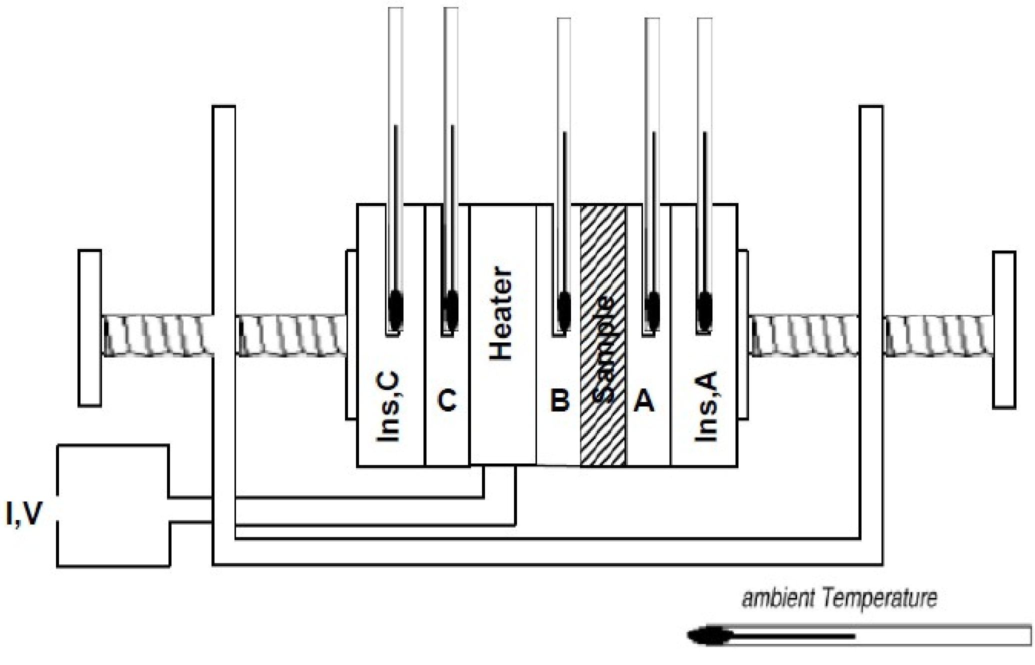


Fig (11) schematic of Lee's disc method