Analysis of Thermal Contact Resistance Across Aluminium Interface Using FEA Method

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Abstract- *In this research the experimental analysis of thermal contact resistance across aluminium interface using finite element method is described and from that, the results obtained are presented. Set-up was fabricated to carry out axial heat flow steady state experiments for the estimation of thermal contact resistance at the interface of two different materials (Aluminium and Copper). For experiment Al plate is used as cooling plate & Cu plate is used as heating plate considering their mechanical and thermal properties. The effects of surface roughness, heat transfer rate, thermal contact resistance, heat generated & heat loss have been studied and acknowledged. The experimental results are expressed in terms of thermal contact resistance and heat transfer rate and compared with theoretical results, showing their limitations to make a precise estimation of the thermal contact resistance. The investigated thermal contact resistance data results are used in various applications of heat transfer.*

Keywords- Thermal contact resistance (TCR), Heat transfer rate, Heat generated, Thermal conductivity.

I. INTRODUCTION

The issue of Thermal Contact Resistance across two different metallic materials shows, when heat flows through two different metallic bodies placed in contact, there is a microscopic temperature discontinuity at the interface. This temperature discontinuity results from thermal contact resistance. This thermal contact conductance at the metal interface can be improved by increasing actual contact area. This can be done by one or more of the following:

(i) Applying high pressure at assemblage.
(ii) By making aluminium contact surface very smooth and flat.
(iii) Using soft interstitial material (soft metal such as Indium, liquid or variety of conductive greases).

Another problem is a potentially great influence of finite Thermal Contact Resistances (TCR) between the sample and other element of the measurement system. This trouble is particularly significant if air is present on the contact surfaces are rough and filled with air. When random rough surfaces are positioned in mechanical contact, then the real contact occurs at the summit of surface asperities which are called microcontacts. TCR in compliance rough surfaces in a vacuum is proportional to the real contact area. When two surfaces are bring into contact, the actual contacting area between the two surfaces is actually only a small part of the total apparent contact surface area and is generally between one and ten percent. Macroscopic contacts are directly dependent on the flatness or waviness of the surfaces in contact and also the degree of surface roughness. A resistance to heat flow produced by this restriction of heat flux lines through these small contacts and the temperature discontinuity results since in effect the heat flow is "delayed" from crossing the interface. This resistance to heat transfer across the interface is defined by,

$$R = (A)\ (\Delta T)/Q$$

Where, R = thermal contact resistance, A = apparent contact surface area,

ΔT = temperature drop across the interface, Q= heat flow rate across the interface

The thermal contact resistance is a function of the temperature level and the apparent contact interface pressure or load. A single perfect contact over part of the apparent contact area is usually considered by analytical approach to the problem of thermal contact resistance.

II. GAP IDENTIFICATION

The factors which determine the real contact area between contiguous solids can be divided into two areas of importance: surface geometry (roughness, waviness) and surface interaction (plasticity, elasticity, hardness). For example, the size of the actual contact area, which depends on the geometrical properties of the contacting surfaces, determines the actual pressure acting on the asperities, while the roughness determines the asperity density over the contacting area. The present knowledge of surface interactions does not allow one to use either the classical elasticity or plasticity theory unless the compressed surfaces are of regular geometrical form with either completely elastic properties or for the case of plasticity without roughness. The most important physical (mechanical) properties are the modulus of elasticity, the hardness or yield pressure of the asperities, and the plasticity in the determination of the following: (i) real contact pressure; (ii) the displacement or approach of the surfaces as a result of the deformation of the surfaces under compression; and (iii) the actual area of contact (number and size of contact spots).

III. OBJECTIVE

(i) Prime objectives of the proposed investigations are to study the concept of the thermal contact resistance (TCR) and parameter involved in the measurement such as temperature across the test specimen, wattage provided to the heating side of test specimen, heat carried away by cooling side of test specimen.

(ii) Study of the factor affecting on the TCR by keeping the other parameter constant which involved the relation between TCR and surface roughness of specimen. Study of the relation of the factor affecting on TCR & heat transfer rate by the graphical method involves graph of heat transfer rate and TCR for the different test specimen having different surface roughness. This method also studies the same concept by using different thermal interface materials between test specimen.

(iii) One of important objectives of this methodology for the experimental set up is to find out remedies to reduce thermal contact resistance so as we can increase heat transfer rate effectively for the industrial applications.

IV. EXPERIMENTS

A. Specification of Experimental Setup:-

Plate 1: Ø150×8mm thick Plate 2: Ø150×8mm thick
Heater: 200 watt (Ø100 ×2mm) Ammeter: 1-5 amps AC Voltmeter: 0-500 volt AC
Heating plate (Copper plate): Ø150 ×20mm thick Cooling plate (Aluminium plate): Ø150 ×20mm thick Thermocouple (K type): bulb (0-400) 0C Temperature indicator: 4 channel (0-400)0C, K type thermocouple input of 0-20mA

B. Experimental Setup:-

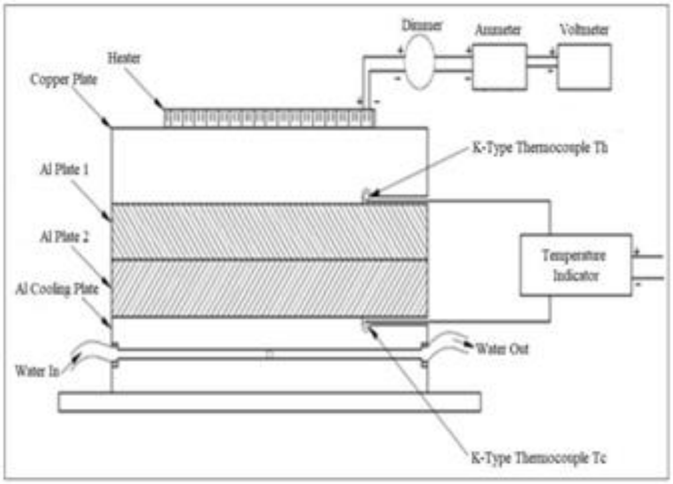


Fig-1. Block diagram of experimental setup

Experimental set up consist the arrangement of the specimen between the heating and cooling side so there is the constant heat flow from the heating to cooling side. The two test specimen are mounted on each other and by arranging the bolting arrangement, pressure is applied on it so the contact between the plates should be air tight. On the heating plate transferring the heat to the test specimen is of the copper. The heater made of the MICA is fixed on the one side and wattage provided to the heater is measured by the voltmeter and ammeter and control of the heat energy provided is by using the dimmer.

On the other side of set up there is cooling arrangement for the rejection of the heat flowing through the test specimen. These cooling arrangement plates are made of aluminium for better cooling. For the fast cooling process water cooling arrangement is done in the plate with the water inlet and outlet arrangement. This whole setup is mounted on the table which is made of the CI square pipe so it gives the rigid support to the experiment.

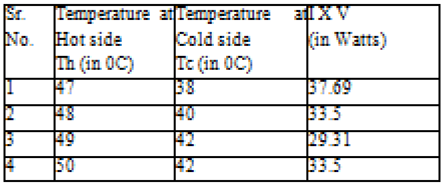
On the one side of this stand support vertical control panel is provided so the parameter required to measure can be seen and also parameter wants to be controlled can be controlled by the switches and meter also mounted on the control panel. This control panel is consisting of temperature indicator for the indication of the temperature across the plate. Ammeter and voltmeter is provided on the panel so it indicates the energy provided to the heater. Dimmer is also mounted on the panel which will control the current provided to the heater.

V. OBSERVATION & CALCULATION

A. Observation Table:-

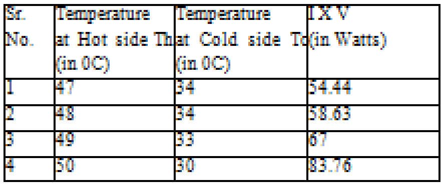
Surface roughness is measured by using the surface roughness measuring instrument and this instrument create the values depending the average of deep and cruest present in measured surface. The different temperature reading taken from test setup. See the following different temperature reading at Surface finish between Al plate-

Table-1. Temperature reading at Surface finish between Al plate Ra=0.625



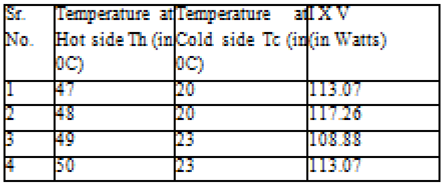
Sr. No.	Temperature at Hot side Th (in 0C)	Temperature at Cold side Tc (in 0C)	I X V (in Watts)
1	47	38	37.69
2	48	40	33.5
3	49	42	29.31
4	50	42	33.5

Table-2. Temperature reading at Surface finish between Al plate Ra=0.125



Sr. No.	Temperature at Hot side Th (in 0C)	Temperature at Cold side Tc (in 0C)	I X V (in Watts)
1	47	34	54.44
2	48	34	58.63
3	49	33	67
4	50	30	83.76

Table-3. Temperature reading at Surface finish between Al plate Ra=0.00



Sr. No.	Temperature at Hot side Th (in 0C)	Temperature at Cold side Tc (in 0C)	I X V (in Watts)
1	47	20	113.07
2	48	20	117.26
3	49	23	108.88
4	50	23	113.07

B. Calculation Part:-

i) Surface Area = $(\pi r^2)/4$ = 3.14 x $0.15^2/4$ =0.01767

ii) Heat Generated
Qgen= A amp x V volts

iii) Heat transfer from cold to hot section Q= kA (Th – Tc)/L

iv) Calculation of TCR= (Temp Diff x Ra Value) / Heat Transfer Rate

a) Calculations at Surface Roughness Value Ra=0.625

1. For 1st Temperature reading, Heat Transfer Rate at Ra=0.625
   =0.237x 0.01767(47-38)/0.0015=25.13w/m^2
   i) Calculation for TCR
   = (47-38) x 0.625/25.13 =0.2238
2. For 2nd Temperature reading, Heat Transfer Rate at Ra=0.625
   =0.237x 0.01767(48-40)/0.0015=22.33w/m^2
   i) Calculation for TCR
   = (48-40) x 0.625/22.33 =0.2239
3. For 3rd Temperature reading, Heat Transfer Rate at Ra=0.625
   =0.237x 0.01767(49-42)/0.0015=19.54w/m^2
   i) Calculation for TCR
   = (49-42) x 0.625/19.54 =0.2239
4. For 4th Temperature reading, Heat Transfer Rate at Ra=0.625
   =0.237x 0.01767(50-42)/0.0015=22.33w/m^2
   i) Calculation for TCR
   = (50-42) x 0.625/22.33 =0.2239

b) Calculations at Surface Roughness Value Ra=0.125

1. For 1st Temperature reading, Heat Transfer Rate at Ra=0.125
   =0.237x 0.01767(47-34)/0.0015=36.29w/m^2
   i) Calculation for TCR
   = (47-34) x 0.125/36.29 =0.0448

c) Calculations at Surface Roughness Value Ra=0.00

1. For 1st Temperature reading,
   Heat Transfer Rate at fluidic media
   =0.237x 0.01767(47-20)/0.0015=75.38w/m^2
   i) Calculation for TCR
   = (47-20) x 0.00/75.38 =0.00

VI. MODELING & ANALYSIS

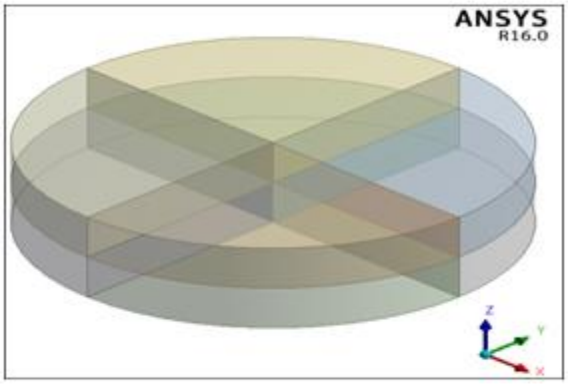


Fig-2. Geometric Model of Aluminium plates.

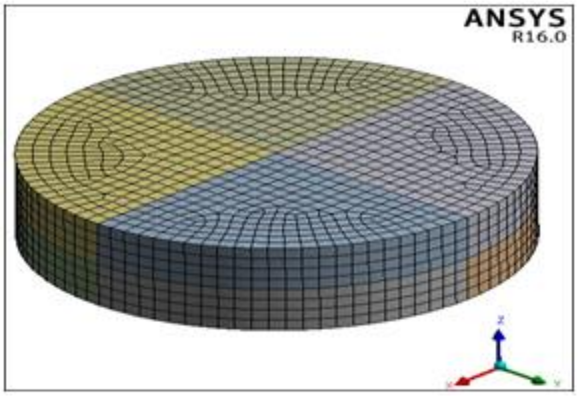


Fig-3. Meshing Geometry

A. Boundary condition same for all cases*:*

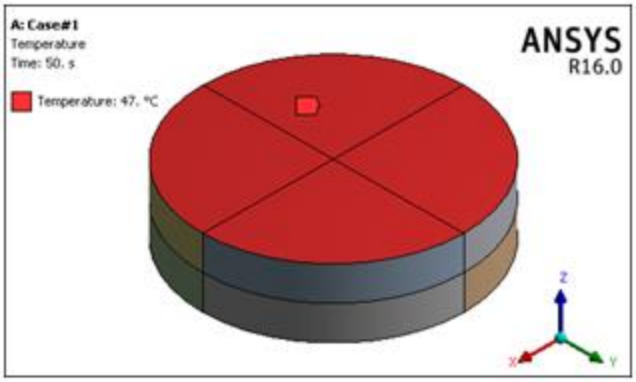


Fig-4. Boundary condition at temperature 470C

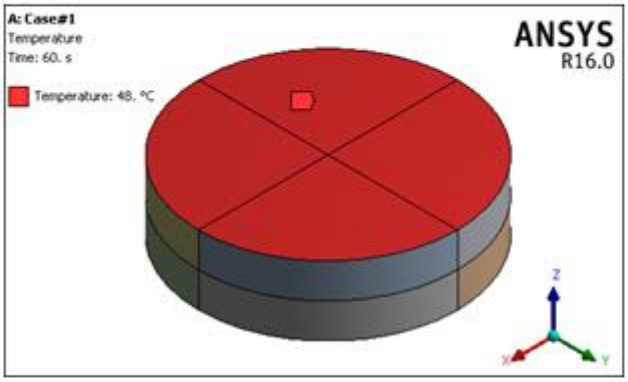


Fig-5. Boundary condition at temperature 480C

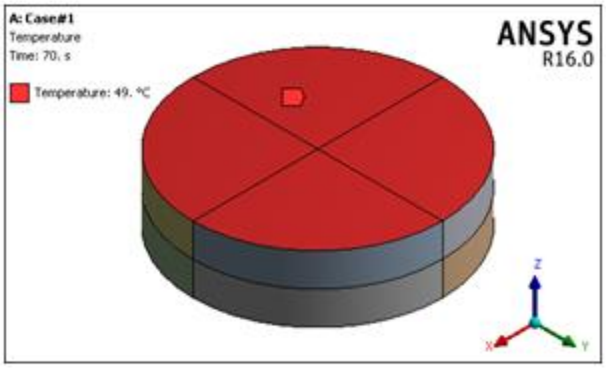


Fig-6. Boundary condition at temperature 490C

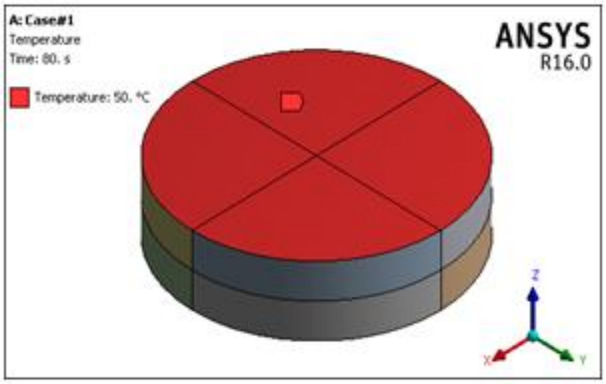


Fig-7. Boundary condition at temperature 500C

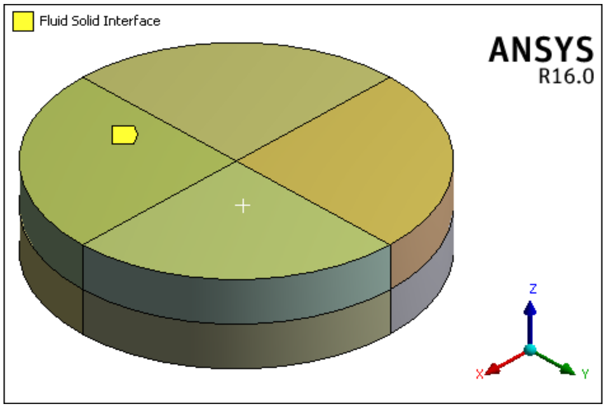
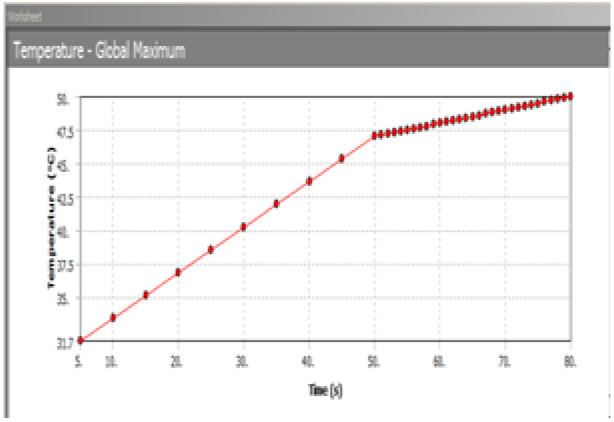
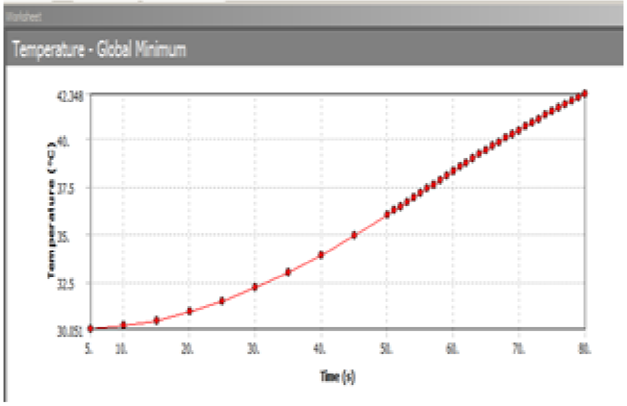


Fig-8. Boundary condition for Cooling Plate

B. Graph of time Vs temperature:



Graph-1. Graph of time Vs temp. at heater side for case 1



Graph-2. Graph of time Vs temp. at cooler side for case 1

C. Result for case 1 at various temperature:

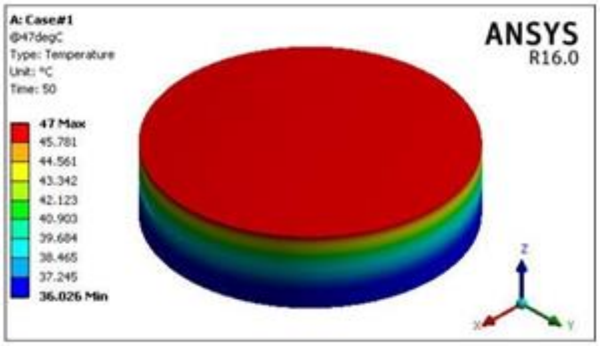


Fig-9. Result at temperature 470C

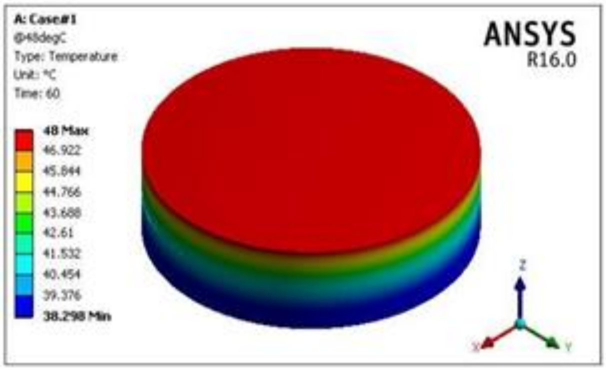


Fig-10. Result at temperature 480C

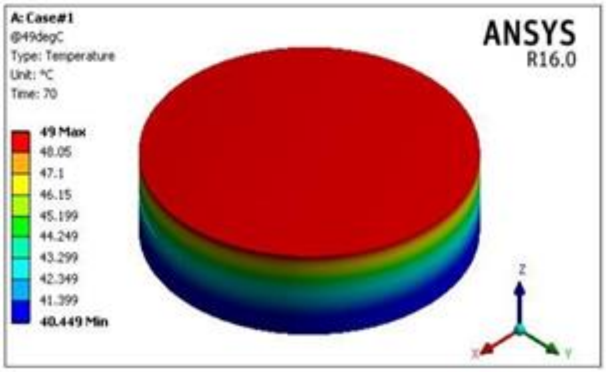


Fig-11. Result at temperature 490C

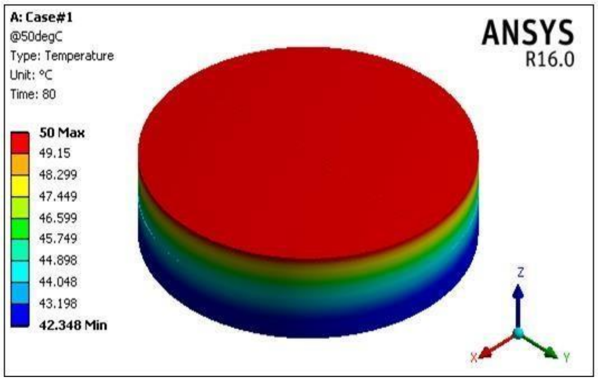


Fig-12. Result at temperature 500C

D. Result for case 2 at 470C temperature:

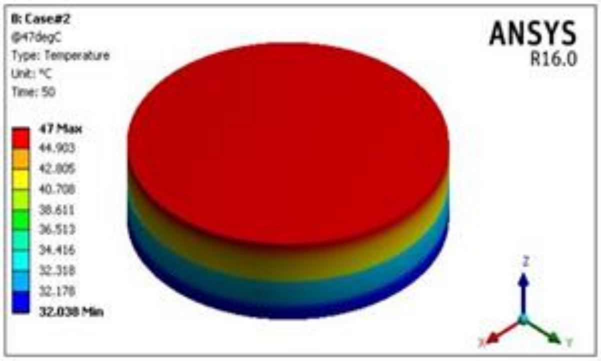


Fig-13. Result at temperature 470C

E. Result for case 3 at 470C temperature:

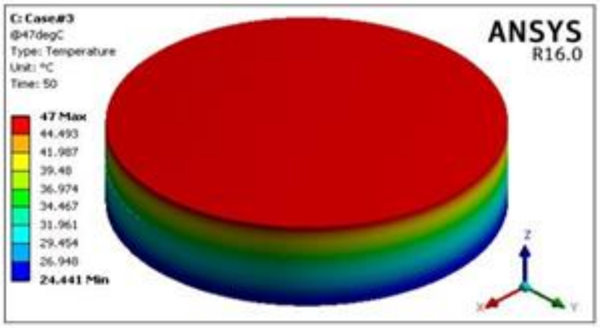


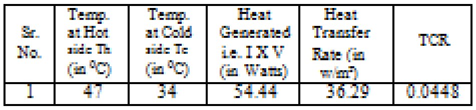
Fig-14. Result at temperature 470C

VII. RESULT & DISCUSSION

Table-4. Result Summary at Surface finish between Al plate Ra=0.625

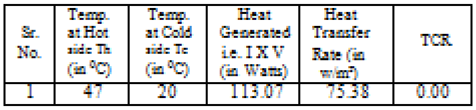
Sr. No.	Temp. at Hot side Th (in °C)	Temp. at Cold side Tc (in °C)	Heat Generated i.e. I X V (in Watts)	Heat Transfer Rate (in w/m²)	TCR
1	47	38	37.69	25.13	0.2239
2	48	40	33.5	22.33	0.2239
3	49	42	29.31	19.54	0.2239
4	50	42	33.5	22.33	0.2239

Table-5. Result at Surface finish between Al plate Ra=0.125



Sr. No.	Temp. at Hot side Th (in °C)	Temp. at Cold side Tc (in °C)	Heat Generated i.e. I X V (in Watts)	Heat Transfer Rate (in w/m²)	TCR
1	47	34	54.44	36.29	0.0448

Table-5. Result at Surface finish between Al plate Ra=0.00

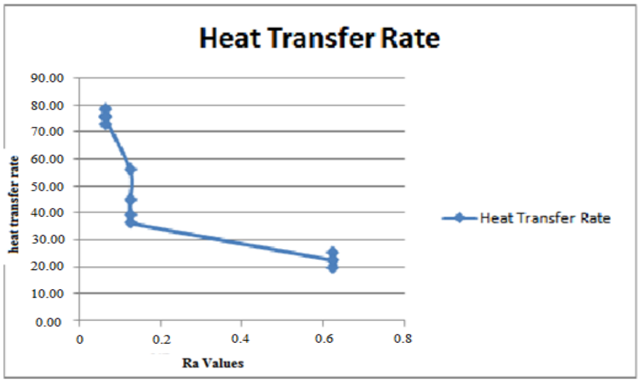


Sr. No.	Temp. at Hot side Th (in °C)	Temp. at Cold side Tc (in °C)	Heat Generated i.e. I X V (in Watts)	Heat Transfer Rate (in w/m²)	TCR
1	47	20	113.07	75.38	0.00

Discussion on Results:-

A. Effect of surface Roughness:-

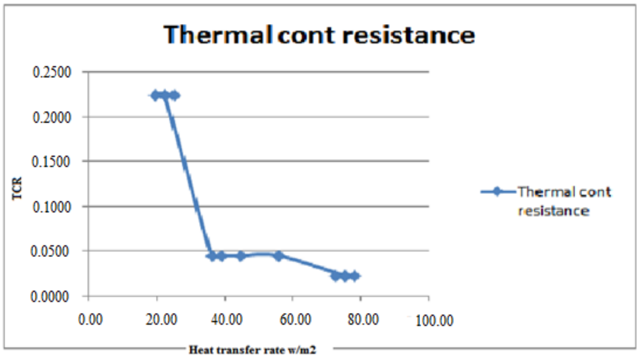
The following Graph: 3- shows heat transfer Vs roughness of surface directly affected each other and relation between them involves the term TCR. At Ra value 0.625 heat transfer rate is 25.13 w/m², at Ra value 0.125 heat transfer rate is 36.29 w/m² & at Ra value 0.00 heat transfer rate is 75.38 w/m². Contacting face between two similar or dissimilar material may largely affect the rate of heat transfer as the high roughness provide more space in between the plate, so it is found that high roughness gives low rate of heat transfer.



Graph-3. Graph of heat transfer rate Vs Ra value

B. Effect of heat transfer rate:-

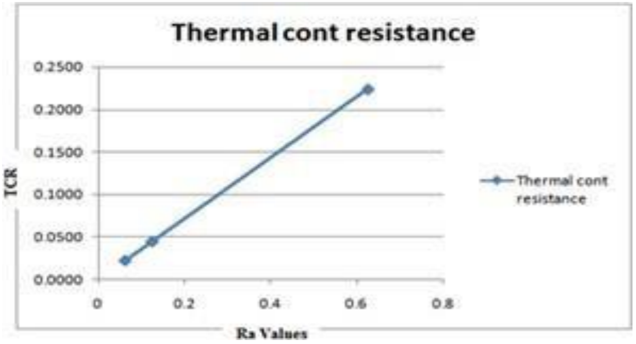
The following Graph: 4- shows when heat transfer rate is increases, thermal contact resistance decreases. For first test, heat transfer rate is 25.13 w/m² & TCR is 0.2238. For second test, heat transfer rate is 36.29 w/m² & TCR is 0.0448. For third test, heat transfer rate is 75.38 w/m² & TCR is 0.00.



Graph-4. Graph of heat transfer rate Vs TCR

C. Effect of thermal contact resistance:-

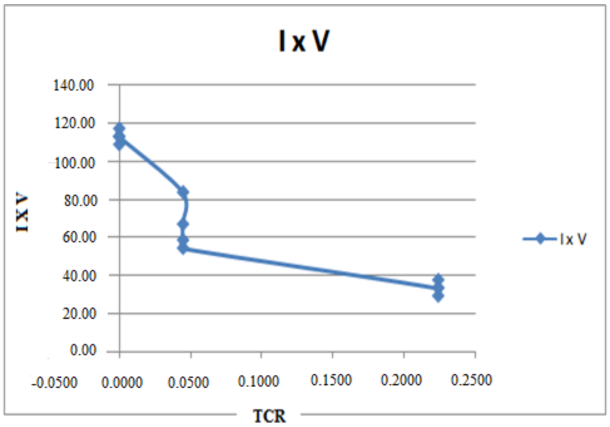
The following Graph: 5- shows as surface roughness increases, thermal contact resistance also increases.



Graph-5. Graph of Ra values Vs TCR

D. Effect of heat generated (I x V):-

The following Graph: 6- shows graph of thermal contact resistance Vs heat generation. Heat loss is the difference between heat generated and heat transfer rate.



Graph-6. Graph of TCR Vs I x V

E. Effect on heat loss:-

As the surface roughness increases the heat loss rate is also reduces. Contacting surface of any two similar/dissimilar material plates are very largely affect the heat loss quantity. Low contact resistance may lead to minimize heat loss.

F. Remedies for maximum heat transfer & minimum heat loss:-

As third reading shows that, putting the fluidic i.e. heat transfer rate through involving the fluid is maximum media reduce the surface roughness and hence increase transfer rate. Providing the good surface or inserting additives like fluidic media can minimize the resistance for heat flow. Whole study shows that, in any energy heat equipments involved in surface contact heat transfer affected majorly due thermal contact resistance that are difficult to calculate.

VIII. CONCLUSIONS

From the present work, the conducted experimental study concludes following points.

i) Surface roughness of aluminium plates is most significance influences on thermal contact resistance and heat transfer rate.
ii) Thermal contact resistance mostly doesn't change with the increase of input voltage of heater and the thermal contact resistance in the experiment with temperature compensation is lower than that the one without temperature compensation.
iii) Thermal contact resistance in the experiment with thermal conductive adhesive at the interface is lower than that the one without thermal conductive adhesive.
iv) The good agreement between experimental and FEA results.

IX. ACKNOWLEDGEMENT

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