Heat transfer analysis of dissimilar magnesium alloy joints

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Abstract— Weight reduction while maintaining functional requirements is one of the major goals of engineering design and manufacturing so that materials, energy, and costs are saved and damage to the environment is reduced. The use of lightweight magnesium (Mg) alloy offers significant potential to improve automotive fuel efficiency. However, the application of formed magnesium alloy components in auto-body structures is restricted due to this material's low formability at room temperature and lack of knowledge for processing magnesium alloys at elevated temperature. In this study, finite element heat transfer analysis has been conducted of dissimilar rectangular plate of Mg alloy AZ31B and HK31A at elevated temperatures.

Keywords— Mg alloy AZ31B and HK31A, ANSYS, Steady state analysis, Heat flow, Thermal flux and Thermal gradient.

I. Introduction

Thermal heating and mechanical stirring originated with probe join two pieces of dissimilar magnesium plates. For light metal alloys, joining is expected in transport industries due to the high quality of the joint because of the low temperature processing without melting. It is considered by many to be the most significant development in metal joining in a decade. Commercial magnesium alloys do not have enough strength to apply for structural materials. However, magnesium alloys are attractive to reduce the weight products are used for products required high strength. Magnesium alloy should be used in the proper portion of the part of structure. The joint of these dissimilar metals required. However, dissimilar joining between AZ31B Mg alloy and HK31A Mg alloy by conventional fusion welding. It is unable because of the vast volume of Mg17Al12 intermetallic compound formation in the fusion zone. The processing temperature during joining process does not reach melting points of the alloys, so the formation of intermetallic compounds in welding zone is limited. In this paper, dissimilar joint between Mg alloy type AZ321B and HK31A magnesium alloys were produced. The heat input ratio and the formation of intermetallic compounds in weld zone was reduced as much as possible. In addition, the heat transfer analysis using ansys software was discussed.

II. Literature Review

[1] Sound weld between 5052 Al alloy and AZ31 Mg alloy could be produced through FSW with a rotation speed of 600 r/min and welding speed of 40 mm/min. Microstructure of the base metal was replaced by equated and fine grains in stir zone. At the top of the stir zone, 5052 and AZ31 alloys were simply bonded, while onion ring structure which consisted of aluminium bands and magnesium bands was formed at the bottom of the stir zone. Micro hardness profiles presented uneven distributions and the maximum value of micro hardness in the stir zone was twice higher than that of the base materials. The fracture position located at a distance of 2.5 mm from the joint centre leaning to the advancing side (aluminium side), where the hardness gradient was the sharpest. et.al dissimilar friction stir welding between 5052 Al alloy and AZ31 Mg alloy with the plate thickness of 6 mm was investigated. Sound weld was obtained at rotation speed of 600 r/min and welding speed of 40 mm/min. Compared with the base materials, the microstructure of the stir zone is greatly refined. Complex flow pattern characterized by intercalation lamellae is formed in the stir zone. Micro hardness measurement of the dissimilar welds presents an uneven distribution due to the complicated microstructure of the weld, and the maximum value of micro hardness in the stir zone is twice higher than that of the base materials. The tensile fracture position locates at the advancing side (aluminium side), where the hardness gradient was sharpest.

[2] The dissimilar FSW joint between A5052-H aluminium alloy and AZ31B magnesium alloy was able to join and the joint efficiency was achieved to 61%. This value was not enough to acquire reliable joints but much higher than that of laser welded joints. It needs to improve the distribution of the intermetallic compounds. The highest hardness of each FSW joint has the linear relation to heat input ratio. The reliable dissimilar Al and Mg FSW joint that has high joint efficiency and elongation could acquire by the lower heat input rate to suppress the formation of Mg17Al12 intermetallic phase.

III. Magnesium Alloy

Magnesium alloy developments have traditionally been driven by aerospace industry requirements for lightweight materials to operate under increasingly demanding conditions. Magnesium alloys have always been attractive to designers due to their low density, only two thirds that of aluminium.

Properties and Advantages Of Magnesium Alloy

- ✓ Light weight.
- ✓ Low density (two thirds that of aluminium).
- ✓ Good high temperature mechanical properties.
- ✓ Good to excellent corrosion resistance.

Many obvious advantages offered by magnesium and its alloys are due to its special characteristics that put it out of comparison. The automotive industry has crossed the threshold from using magnesium in a protected environment, predominantly interior applications to an unprotected environment. Production magnesium components currently emphasize interior applications, such as steering column brackets, instrument panel, seat frames, steering wheel, and sunroof track assembly etc. However, some modern applications expand magnesium's domain to roof panels, hood, rear deck lid, wheels, intake manifold, cylinder head cover, oil pan, starter/alternator, and engine block.

Joining Of Magnesium Alloys

Many standard magnesium alloys are easily welded by gas or resistance-welding equipment, but cannot be cut with an oxygen torch. Magnesium alloys are not welded to other metals, because brittle inter-metallic compounds may form, or because the combination of metals may promote corrosion. Where two or more parts are welded together, their compositions must be the same. Magnesium alloys containing small amounts of aluminium, manganese, zinc, zirconium, etc., have strength equaling that of mild steels. They can be rolled into plate, shapes, and strip. Magnesium can be cast, forged, fabricated, and machined. As a structural metal it is used in aircraft. It is used by the materials-moving industry for parts of machinery and for hand-power tools due to its strength to weight ratio. Magnesium can be welded by many of the arc and resistance welding processes, as well as by the oxyfuel gas welding process, and it can be brazed. Magnesium like aluminium is produced with different tempers. These are based on heat treatment and work hardening. The strength of a weld joint is lowered in base metal, in the work-hardened condition, as a result of recrystalization and grain growth in the heat-affected zone. This effect is minimized with gas metal arc welding because of the higher welding speed utilized. This is not a factor in the base metals that are welded in the soft condition. Magnesium possesses properties that make welding it different than the welding of steels. Many of these are the same as for aluminium. These are:

- ✓ Magnesium oxide surface coating.
- ✓ High thermal conductivity.
- ✓ Relatively high thermal expansion coefficient.
- ✓ Relatively low melting temperature.

Classification Of Magnesium Alloy

Magnesium alloys names are often given by two letters following by two numbers. Letters tell main alloying elements (A = aluminium, Z = zinc, M = manganese, S = silicon). Numbers indicate respective nominal compositions of main alloying elements.

- ✓ Cast alloys.
- ✓ Wrought alloys.
- ✓ Elektron.
- ✓ Magnox.
- ✓ Magnuminium.

Table No. 1 Properties Of Two Dissimilar Magnesium Alloy For This Project

- ✓ **Mg_AZ31B-H24.**
- ✓ **Mg_HK31A-H24.**

s.no	MECHANICAL PROPERTIES	Units	AZ31B	HK31A
1	Density	(g/cc)	1.78	1.8
2	ULTIMATE Tensile Strength	Mpa	241 - 290	255
3	YIELD Tensile Strength	Mpa	150 - 220	180
4	Hardness, Brinell	-	46 - 73	55
5	Hardness, Rockwell A	-	-	-
6	Hardness, Rockwell B	-	-	-
7	Youngs Modulus	Gpa	-	45
8	Shear Strength	Mpa	-	-
9	Shear Modulus	Gpa	-	17
THERMAL PROPERTIES		Units	AZ31B	HK31A
10	Thermal Conductivity	(W/m-K)	84	92
11	Specific Heat Capacity	J/g-°C	1.05	1
12	Melting Point	°C	640 - 680	650 - 680
13	CTE, linear	µm/m-°C	26	26.8
14	Heat of Fusion	J/g	-	325
CHEMICAL PROPERTIES		CH Name	AZ31B	HK31A
15	Magnesium	Mg	96%	96%
16	Aluminum	Al	3%	-
18	Zinc	Zn	1%	<= 0.30 %
19	Copper	Cu	-	<= 0.10 %
20	Nickel	Ni	-	<= 0.010 %
21	Manganese	Mn	-	2.5 - 4.0 %
22	Iron	Fe	-	0.40 - 1.0 %
ELECTRICAL PROPERTIES		Units	AZ31B	HK31A
23	Electrical Resistivity	ohm-cm	9.2E-06	0.0000077

IV. Experimental Procedure

Two dissimilar Magnesium alloy AZ31B and HK31A of thickness 6 mm was selected as work piece material. Mg plate with dimension of 60 mm x 50 mm.

Using Pro-e software to draw two plates with dimensions of 60mm x 50mm x 6mm with v-groove shape. After drawn save the file in IGES format.

Import IGES format file to ansys software, to analyse heat transfer between two dissimilar magnesium alloy plates in ansys software.

V. Heat Transfer Analysis Using Ansys Software

Steady-State Thermal Analysis

The steady-state thermal analysis to determine temperatures, thermal gradients, heat flow rates, and heat fluxes in an object that are caused by thermal loads that do not vary over time. Such loads include the following:

- ✓ Convections
- ✓ Radiation

- ✓ Heat flow rates
- ✓ Heat fluxes (heat flow per unit area)
- ✓ Heat generation rates (heat flow per unit volume)
- ✓ Constant temperature boundaries.

A steady-state thermal analysis may be either linear, with constant material properties; or nonlinear, with material properties that depend on temperature. The thermal properties of most material do vary with temperature, so the analysis usually is nonlinear. Including radiation effects also makes the analysis nonlinear.

VI. Tasks in a Thermal Analysis

The procedure for doing a thermal analysis involves three main tasks:

- ✓ Build the model.
- ✓ Apply loads and obtain the solution.
- ✓ Review the results.

VII. Build The Model

To build the model, you specify the job name and a title for your analysis. Then, you use the ANSYS pre-processor (PREP7) to define the element types, material properties (export from matweb.com), and the model geometry. These tasks are common to most analyses.

For a thermal analysis, you also need to keep these points in mind:

Element Type

To specify element types, you use either of the following:

Main Menu>Pre-processor>Element Type>Add/Edit/Delete
Select, Solid - 8 Nodes.

Export Material

Export materials from matweb.com to ansys software material library in computer C drive. Add materials in ansys software material library path option. Select two magnesium alloy material from material library.

Creating Model Geometry and Meshing Operation

Import drawn IGES file to ansys software. Pick all and meshing.

Applying Loads and Obtaining the Solution

You must define the analysis type and options, apply loads to the model, specify load step options, and initiate the finite element solution.

Defining the Analysis Type

During this phase of the analysis, you must first define the analysis type:

- ✓ In the GUI, choose menu path **Main Menu>Solution>New Analysis>Steady-state (static).**

VIII. Applying Loads

Apply loads either on the solid model (key points, lines, and areas) or on the finite element model (nodes and elements). You can specify loads using the conventional method of applying a single load individually to the appropriate entity, or you can apply complex boundary conditions via TABLE type array parameters. You can specify types of thermal loads:

Constant Temperatures (TEMP)

These are DOF constraints usually specified at model boundaries to impose a known, fixed temperature.

Heat Flow Rate (HEAT)

These are concentrated nodal loads. Use them mainly in line-element models (conducting bars, convection links, etc.) where you cannot specify convections and heat fluxes. A positive value of heat flow rate indicates heat flowing into the node (that is, the element gains heat). If both TEMP and HEAT are specified at a node, the temperature constraint prevails..

Heat Fluxes (HEAT)

Heat fluxes are also surface loads. Use them when the amount of heat transfer across a surface (heat flow rate per area) is known, or is calculated through a FLOTRAN CFD analysis. A positive value of heat flux indicates heat flowing into the element. Heat flux is used only with solids and shells. An element face may have either CONV or HFLUX (but not both) specified as a surface load. If you specify both on the same element face, ANSYS uses what was specified *last*.

Thermal gradient (HGEN)

Apply heat generation rates as "body loads" to represent heat generated within an element, for example by a chemical reaction or an electric current. Heat generation rates have units of heat flow rate per unit volume.

IX. Solving The Model

Main Menu>Solution>Current LS

Solution is done.

X. Reviewing Analysis Results

ANSYS writes the results from a thermal analysis to the thermal results file, *Jobname*.RTH. Results contain the following data:

Primary data

- ✓ Nodal temperatures (TEMP)

Derived data

- ✓ Nodal and element thermal fluxes (TFX, TFY, TFZ, TFSUM)
- ✓ Nodal and element thermal gradients (TGX, TGY, TGZ, TGSUM)
- ✓ Element heat flow rates
- ✓ Nodal reaction heat flow rates
- ✓ ...etc.

I review these results using the general postprocessor, POST1 (The GUI menu path is **Main Menu>General Postproc**.

Reviewing Results

The ANSYS graphics displays and tables to review them. To display your results, use the following menu paths. Equivalent commands are shown in parentheses.

MainMenu>GeneralPostproc>PlotResults>ElementSolu
MainMenu>GeneralPostproc>PlotResults>ElemTable
Main Menu>General Postproc>Plot Results>Nodal Solu.

XI. ANALYSE VALUE

Table No. 2 Heat Flow

S.No.	TEMPEARTURE	HEAT FLOW				
		Minimum value		Maximum value		Average Values
	°K	Btu (th)/s (Analytical value)	Watts (SI units)	Btu (th)/s (Analytical value)	Watts (SI units)	Watts (SI units)
1	600	$-0.179X10^{-9}$	1.89E-07	$0.184X10^{-9}$	1.94E-07	1.91E-07
2	620	$-0.188X10^{-9}$	1.98E-07	$0.159X10^{-9}$	1.68E-07	1.83E-07
3	635	$-0.167X10^{-9}$	1.76E-07	$0.185X10^{-9}$	1.95E-07	1.86E-07
4	650	$-0.133X10^{-9}$	1.40E-07	$0.159X10^{-9}$	1.68E-07	1.54E-07

Figure No.1 Heat Flow At 600^0K

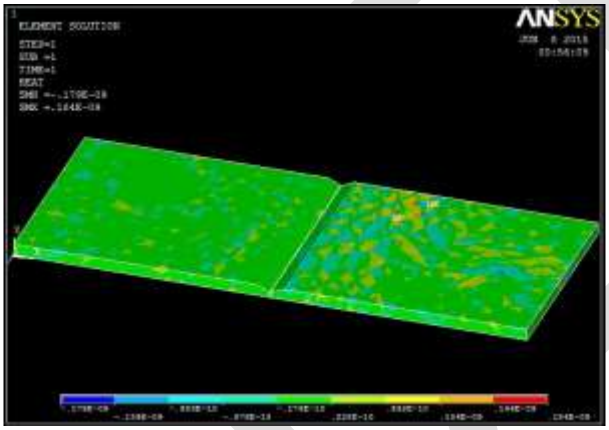


Figure No.2 Heat Flow At 620^0K

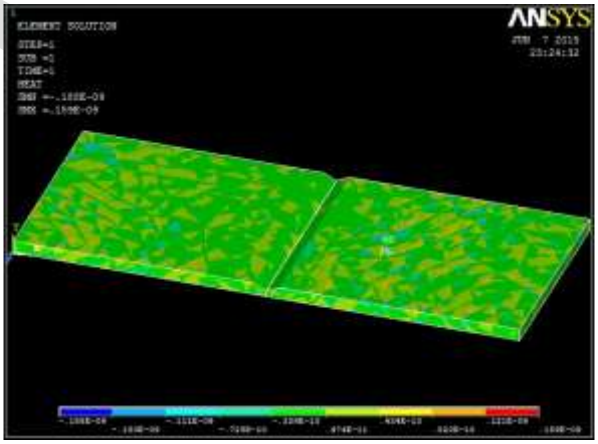


Figure No.3 Heat Flow At 635^0K

Figure No.4 Heat Flow At 650^0K

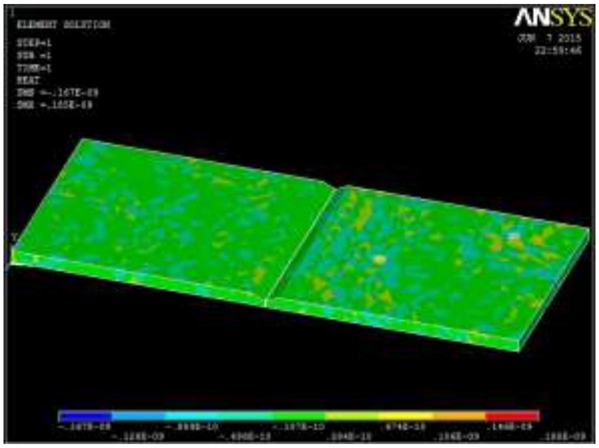


Figure No.5 Thermal Flux At 600^0K

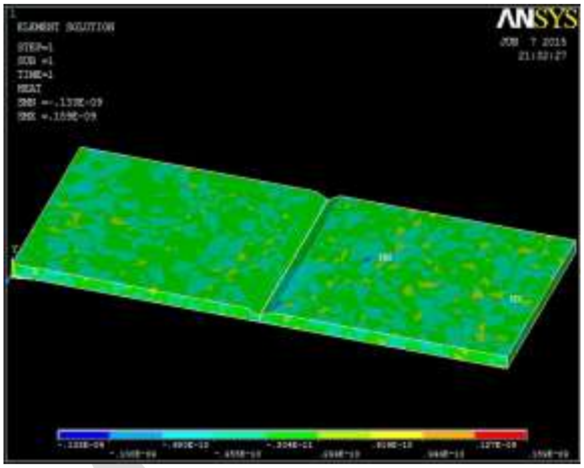


Figure No.6Thermal Flux At 620^0K

Graph No.1 Graph Temp vs Heat flow

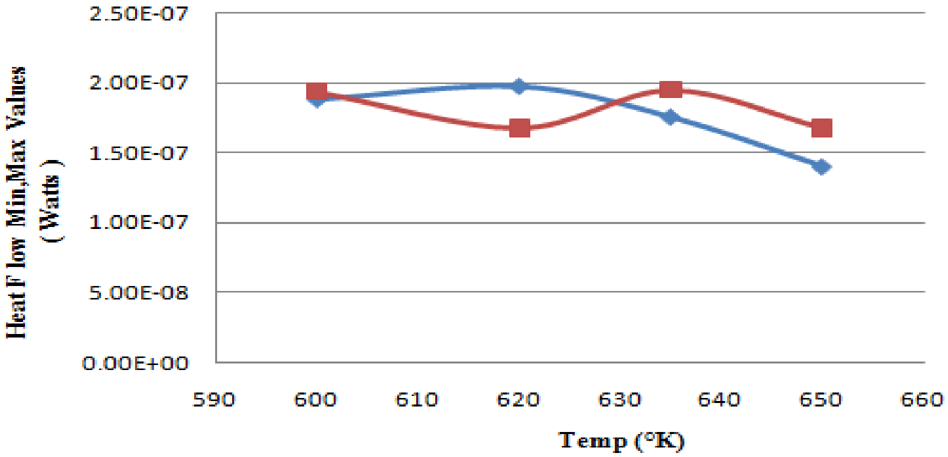


Table No. 3 Thermal Flux

S.No.	TEMPEARTURE	THERMAL FLUX				
		Minimum value		Maximum value		Average Values
	°K	Btu (th)/(s.in2) (Analytical value)	W/m^2 (SI units)	Btu (th)/(s.in2) (Analytical value)	W/m^2 (SI units)	W/m^2 (SI units)
1	600	0.166X10^{-11}	2.713E-06	0.668X10^{-10}	1.09E-04	5.59E-05
2	620	0.125X10^{-11}	2.043E-06	0.916X10^{-10}	1.50E-04	7.59E-05
3	635	0.253X10^{-11}	4.135E-06	0.614X10^{-10}	1.00E-04	5.22E-05
4	650	0.154X10^{-11}	2.517E-06	0.650X10^{-10}	1.06E-04	5.44E-05

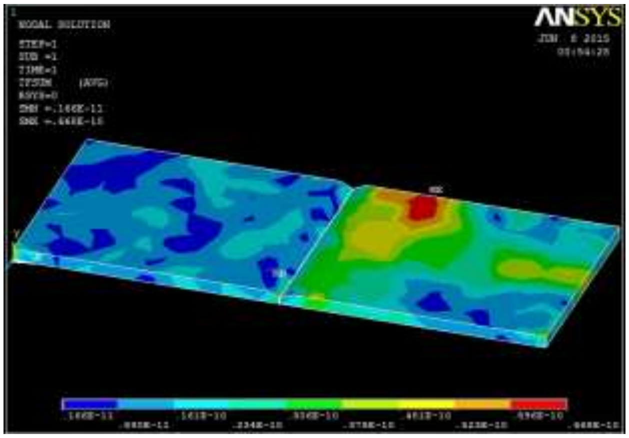


Figure No.7 Thermal Flux At 635^{0}K

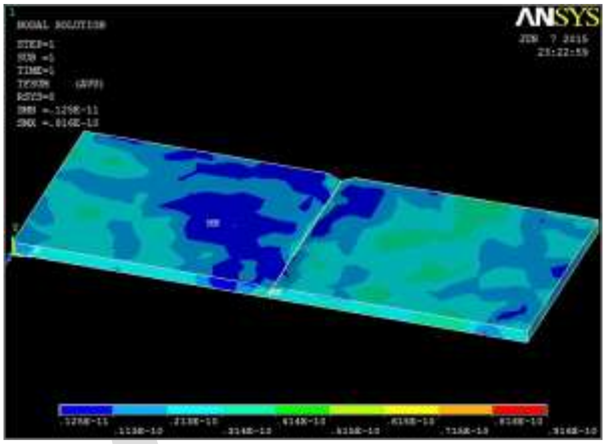
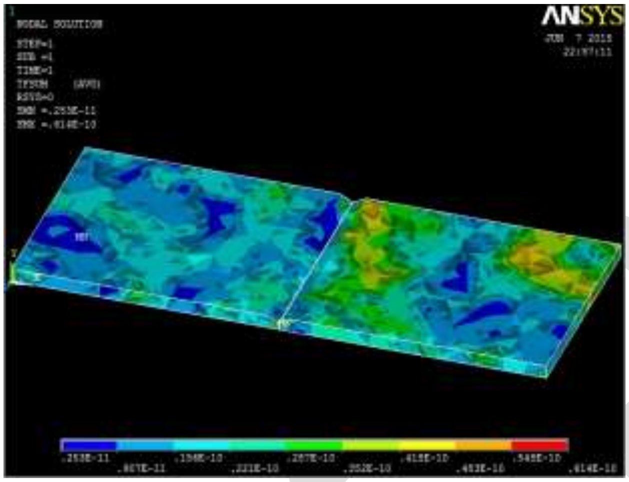
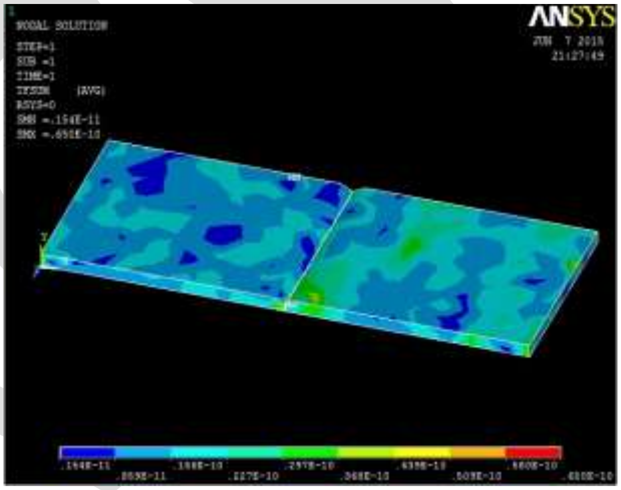


Figure No.8 Thermal Flux At 650^{0}K





Graph No.2 Graph Temp vs Thermal Flux

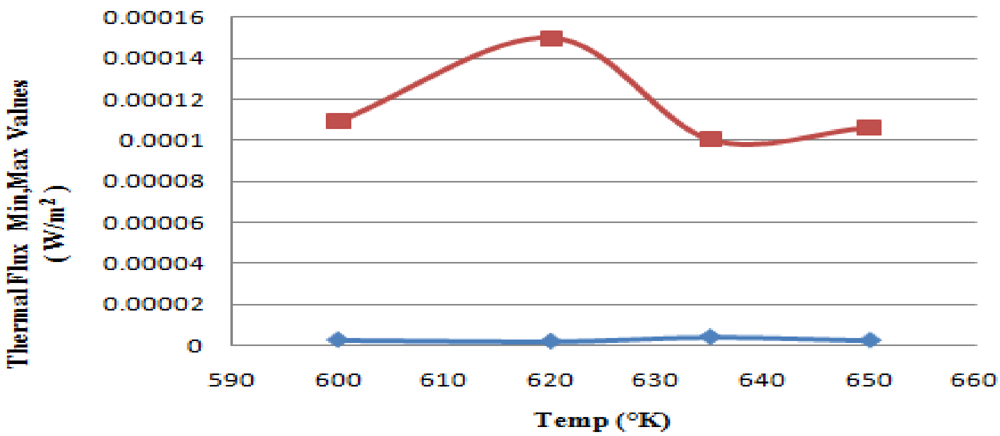


Table No. 4 Thermal Gradient

S.No.	TEMPEARTURE	THERMAL GRADIENT				
		Minimum value		Maximum value		Average Values
	°K	F / inch (Analytical value)	^{0}C/m (SI units)	F / inch (Analytical value)	^{0}C/m (SI units)	^{0}C/m (SI units)
1	600	0.174X10^{-13}	3.17E-14	0.586X10^{-12}	1.07E-12	5.49E-13

2	620	$0.123X10^{-13}$	2.24E-14	$0.962X10^{-12}$	1.75E-12	8.87E-13
3	635	$0.235X10^{-13}$	4.28E-14	$0.645X10^{-12}$	1.17E-12	6.08E-13
4	650	$0.162X10^{-13}$	2.95E-14	$0.683X10^{-12}$	1.24E-12	6.36E-13

Figure No.9 Thermal Gradient At 600^{0}K

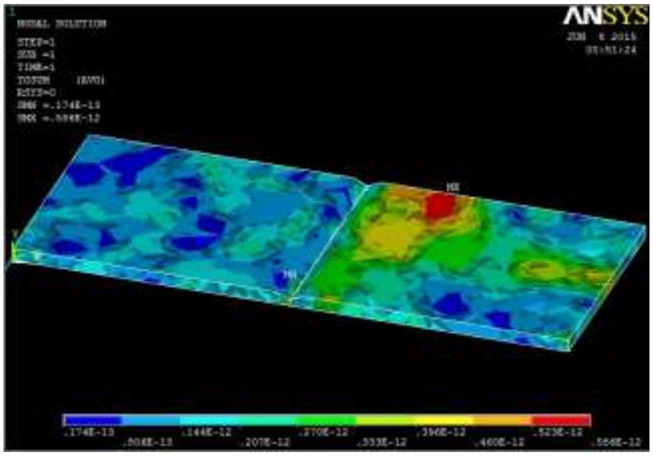


Figure No.10 Thermal Gradient At 620^0 K

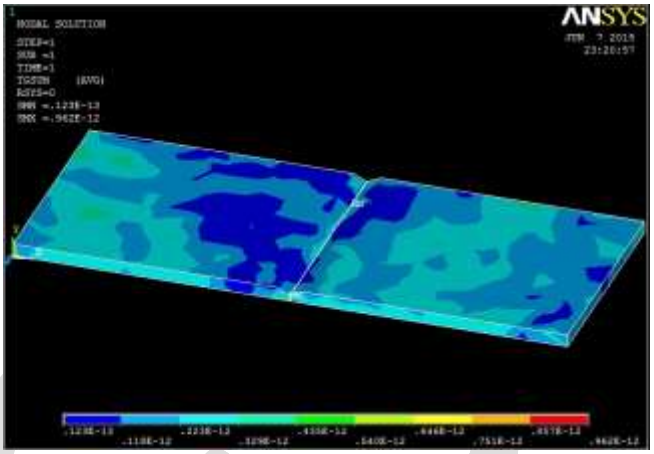


Figure No.11Thermal Gradient At 635^{0}K

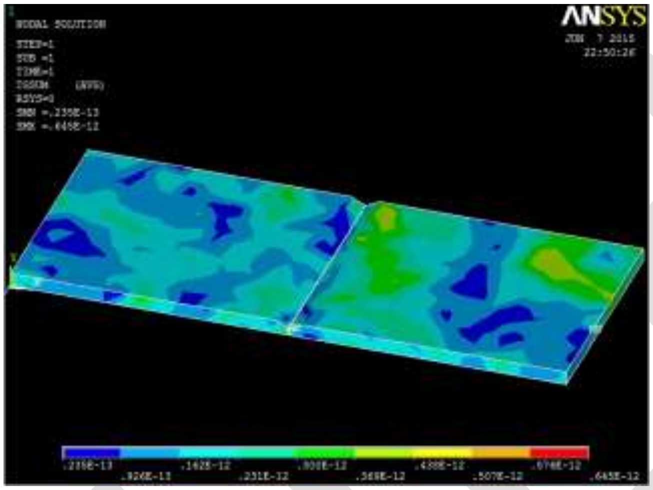
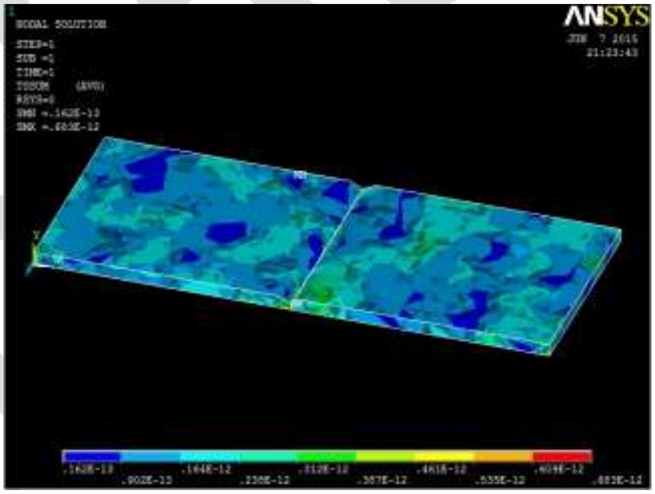


Figure No.12 Thermal Gradient At 650^{0}K



Graph No.3 Graph Temp vs Thermal Gradient

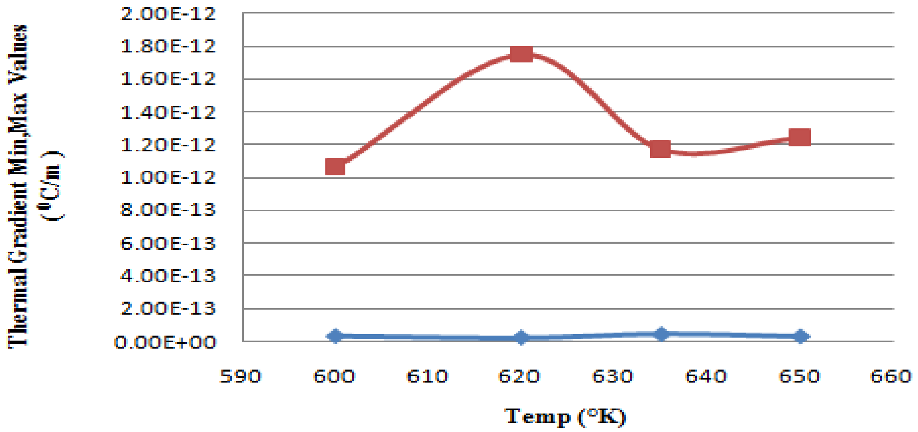
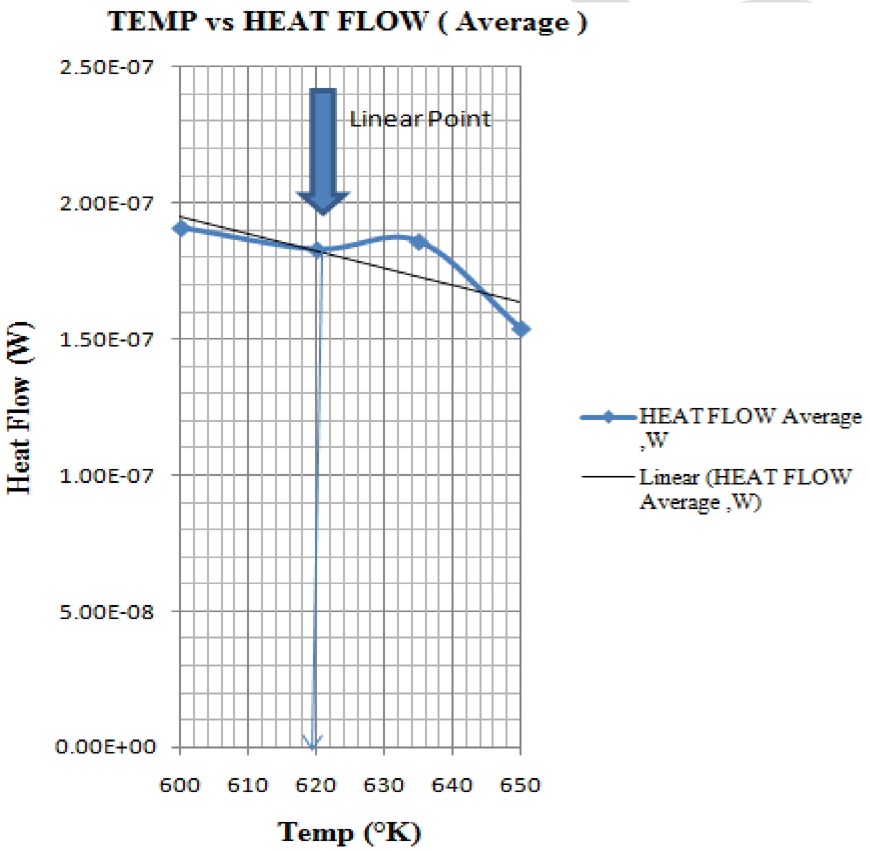


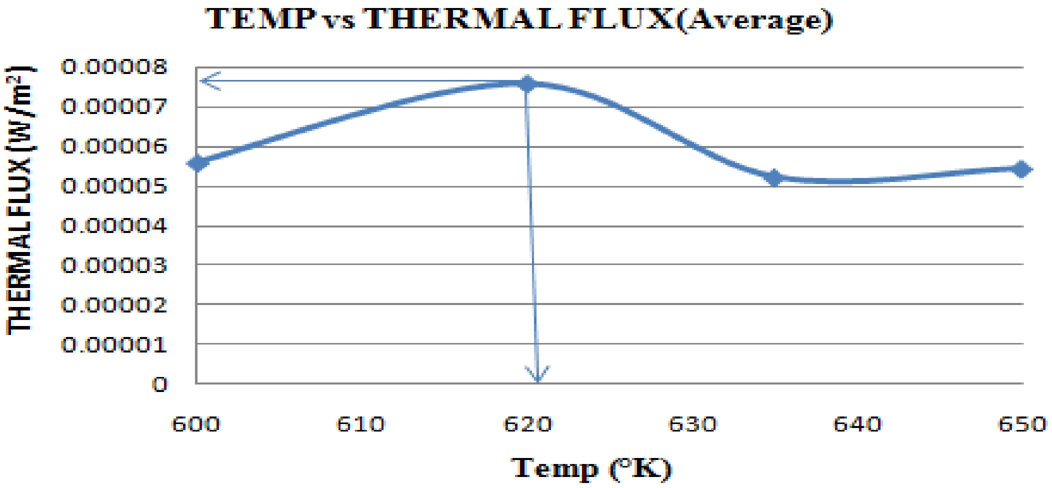
Table No. 5 AVERAGE ANALYTICAL VALUES

S.No.	TEMPEARTURE ^{0}K	HEAT FLOW W	THERMAL FLUX W/m^2	THERMAL GRADIENT ^{0}C/m
1	**600**	1.91E-07	5.59E-05	5.49E-13
2	**620**	**1.83E-07**	**7.59E-05**	**8.87E-13**
3	**635**	1.86E-07	5.22E-05	6.08E-13
4	**650**	1.54E-07	5.44E-05	6.36E-13

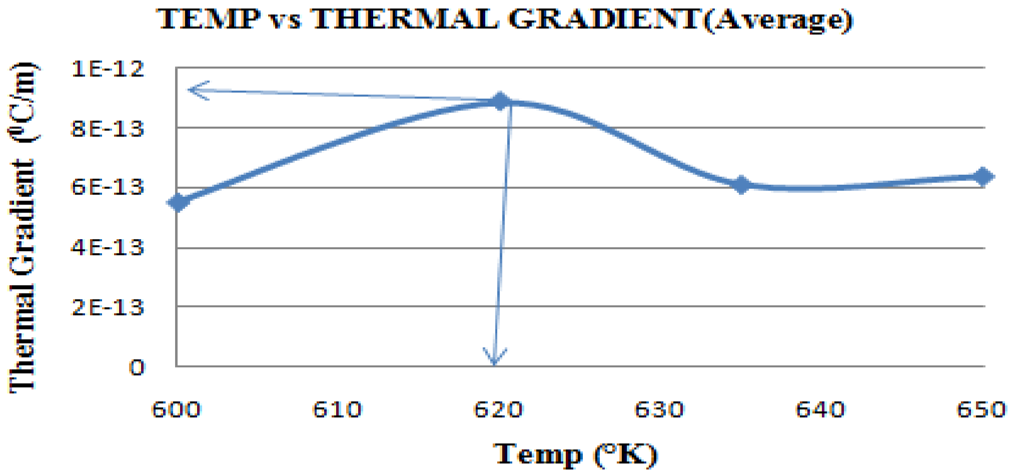
Graph No.4 Graph Temperature vs Average values of Heat Flow



Graph No.5 Graph Temperature vs Average values of Thermal Flux



Graph No.6 Graph Temperature vs Average values of Thermal Gradient



RESULT & CONCLUSION

The graph shows (Graph no.4), Heat flow rate at 620^0**K** is reached linear point. Thermal flux and thermal gradient values (Table no. 5) are high compared to other temperatures. The analytical values and graphical representation shows to join two dissimilar magnesium alloy of AZ31B and HK31A with temperature of 620^{0}K will give a good strength in joining process.

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