BACHELOR IN ENGINEERING PROJECT REPORT

ON

"RESEARCH AND DEVELOPMENT ON LASER WELDING OF ALUMINUM 6063 TO ALUMINUM 6063 ON LITHIUM- ION BATTERY"

BY

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DISCIPLINE OF MECHANICAL ENGINEERING

Ahmedabad University

SCHOOL OF ENGINEERING & APPLIED SCIENCE. AHMEDABAD UNIVERSITY, AHMEDABAD MAY2021

“RESEARCH AND DEVELOPMENT ON LASER WELDING OF ALUMINUM 6063 TO ALUMINUM 6063 ON LITHIUM- ION BATTERY”

A PROJECT REPORT

Submitted in partial fulfilment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY IN MECHANICAL ENGINEERING

Submitted by

DHRUV JAIN------1743054

Guided by

DR. SHASHI PRAKASH – ASST.PROFESSOR

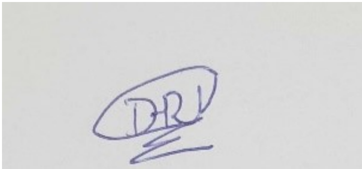
Ahmedabad University

MAY 2021

CANDIDATE DECLARATION

We hereby declare that the project entitled "RESEARCH AND DEVELOPMENT ON LASER WELDING OF ALUMINUM 6063 TO ALUMINUM 6063 ON LITHIUM- ION BATTERY" submitted in partial fulfilment for the award of the degree of Bachelor of Technology in Mechanical Engineering completed under the supervision of Doctor Shashi Prakash, Ahmedabad University is an authentic work.

Further, we declare that We have not submitted this work for the award of any other degree elsewhere. We certify that whenever We have used materials (data, images, theoretical analysis, and text) from other sources, we have given full credit to them in the text of the report and giving their details in the references.



(DHRUV JAIN)

Signature and name of the students with date

(Date: 10/5/2021)

CERTIFICATE BY PROJECT GUIDE(S)

It is certified that the above statement made by the student is correct to the best of our knowledge.

Signature: Dr Shashi Prakash

Date:10/5/2021

Designation: Assistant professor

CERTIFICATE FROM COMPANY

SLTL Group

SLTL/HR/EXP/20-21/42

Date: 30-04-2021

To Whom It May Concerns

This is to certify that **Mr. Dhruv Pankaj Jain** from **School of Engineering and Applied Science (SEAS), Ahmedabad University** has successfully completed his Industrial Internship as a **Trainee** in our **Design and Quality** department from **22/12/2020 to 30/4/2021.**

Moreover, during his tenure with us, we find him hardworking, sincere and punctual at all and to the best of our knowledge he possesses good moral.

We wish him a good luck for his all-future endeavors.

For, Sahajanand Laser Technology Ltd.

Chaudhari

Authorized Signatory

Sahajanand Laser Technology Limited * CIN NO. U30007GJ2002PLC040659

Date: 30-04-2021
Place: Gandhinagar.

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"I am not what happened to me, I am what I choose to become"

– Christopher Gardner, The Pursuit of Happiness.

It is always a pleasure to remind the fine people who guided me in the industrial training program. I received to uphold my practical and theoretical skills during the respective session. Firstly, I would like to thank **Dr. Arvind Patel (Chairman of Sahajanand Laser Technology) and Mr. Mayank Patel (Executive Director)** who recognized and offered me to work with SLTL Group. I would also like to thank Mrs. Purv Patel (Design Head), Mukesh Patel (HR head), Devang (PPC committee), raj and Pranav. In addition, it is important to have teamwork during my training and here I really want to thank my colleagues for their kindness, exchange ideas and knowledge during my training. Last but not least, I want to thank my family for their love, motivation and support during my industrial training in **SLTL**. Thanks for all the ideas, opinion, knowledge and suggestion that have given to me in order for me to complete this report.

We would like to express our special thanks of gratitude to our mentor Dr. Shashi Prakash who gave us golden opportunity to do this project. We are very thankful to Ahmedabad University for giving us the opportunity to pursue this project. It is their help and support, due to which we became able to complete the research and development report. Without their support this report would not have been possible.

ABSTRACT

Laser welding itself was challenging as there was no formal data available much on the internet and due to material properties, it gets much harder to laser weld due to its high reflection, thermal conductivity, and low absorption. It gets more difficult for a person to found the correct way to weld at what speed and power. However, I glad that my industrial training in "Sahajanand laser technology ltd. sector 26, Gandhinagar 382024" has provided me the resources to make that possible with effective measurements.

I came to know about different operations arranged in sequence to meet the product completion on time. Many technologies were seen on the premises and all the machines and operations differed from each other. Moreover, the company used its own laser cutting machine (LCM) to produce their laser cutting machine (LCM), laser marking, and laser welding machine. Laser welding includes various criteria before actually welding two metals together. The welding parameter differs from material to material. In this report, some images and weld quality were mentioned according to standards and review in detail. The ion lithium battery has had 22 cells connected in parallel connection. The plate was kept on those terminals and then welded. While doing this experiment we observe the linear working of laser machine, power vs depth relationship

The machine capacity was capable of up to 3 kW in 3 directional axis the moment was in x, y, and z-direction. The laser head can only move in the z-direction and rest in the x and y direction as 3-d printer machine. The machine was capable of performing the 10,000-feed rate speed (mm/min). The major task was to found the power, distance between the weld material to beamed head, cycle time, the speed with the percentage of duty cycle, and penetration of weld bend. After analysing the review paper and working practically on the machine one can find the parameters according to requirement. The defects in the weld are identified and tried to eliminate. After finding the parameters according to the requirements of the company we need to do this on an actual lithium-ion battery. The plate of AL is kept on battery and then they both are welded using a laser machine. The fixture was also designed by the company to reduce gaps during welding. Overall, the plate thickness was mm and the terminal thickness was 1.5mm. overall the thickness of laser welding is 3mm and its position to weld is spot/lap weld. One needs to be accurate while doing laser welding because if the weld line goes in the wrong direction/more penetration achieves formerly needs then the liquid lithium-ion will come out from that battery any battery will be damaged. There were some recent developments were going on laser welding and trying to make a library to find out the perfect welding parameters for different material.

IMPORTANT KEYWORDS:

- Aluminum material
- Laser welding
- Power
- Depth of penetration
- Lithium-ion battery

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1.0 INTRODUCTION

1.1) COMPANY PROFILE.

The company **"SAHAJANAND LASER TECHNOLOGY"** was established on 1990 in Gandhinagar. The factory was established in 1992 in Gandhi-Nagar and it was the first laser fabrication company introduced in India. Firstly, it introduced laser system for assisting diamond industries. Then from 1995 the company ventured to Laser cutting, Laser marking and engraving, Laser Welding, Micro Machining, Solar Cell Scribing/Cutting etc using integrating with CNC technology. The company have ventured worldwide and is exporting to USA, Russia, Sri Lanka, Thailand, Namibia, Botswana, Saudi Arabia, Iran, Dubai, Switzerland, Angola, Israel, Armenia, China, Poland, South Africa, Singapore and others. The products are running successfully with minimal maintenance and service. Company takes special care in providing products - which are cost effective, production specific, quality conscious and with increased efficiency. It also takes special efforts towards operator training and education. The company is willing to take 3 major aspects as

Vision: We believe in continuous innovation & challenging our capabilities to deliver high tech solutions valuable for all strata of Industry.

Mission: Sahajanand laser technology is committed to bring the best innovation, reliable products, service and total solution to customers for global market with strong coordination & learnings of cross-functional department through its world class manufacturing practices & best in class work culture to attain customer delight.

Values: Building Human Organisation, Universal Tolerance and Acceptance, Empowering Employees to Act, Creating Openness in Communication, Facilitating Ownership of Process and Outcome, promoting a Culture of Collaboration, Promoting Enquiry and Continuous Learning

Figure 1 Sahajanand laser tech ltd. 1

1.2) INTRODUCTION TO LASER WELDING.

When two different types or same type of material is joined together by melting its surface is known as welding. The thesis is the result of theoretical and experimental research into the nature of deep welding of fibre laser welding process with emphasis on the weld shape. the introduction is divided into several parts

- General notes
- Laser welding mechanisms
- Executive summary of the appended papers

1.2.1) GENERAL NOTES

Laser welding technique is more accelerating than other conventional joining technique so some of the advantages might include like low thermal distortion of work piece due to low heat input but in some cases, it might require high in put at some point of time according to penetration required in welding. High speed in laser welding can be achieved up to several meter per second. One laser can be share by several workstation like cutting, marking, heat treatment and more. Weld line or band can be achieved as one desires to obtain the structure. Complex material configuration and dis similar metals can be welded. In some cases, one can pre heat the weld metal and then use laser welding so more precise and accurate weld line can be configured. Laser welding is suited to automation and can also operate in conjunction with robots.

1.2.2) LASER WELDING MECHANISMS

Welding is of two types of laser welding mechanism concentrated and key hole welding mechanism. For the discussion we can simply consider that laser itself is a heating device.

A) CONDUCTION WELDING

The laser beam irradiates the material surface and heat are conducted radially away from the laser material interaction zone. The molten pool of melted metal has established a semi-circular type cross section as shown in **figure2**. The depth to width ratio of welds of this sort gives them a higher tolerance to poor up than keyhole type welds. As a joining process however, conduction limited welding is far less efficient than keyhole welding in terms of energy consumed per unit area of join in terms of deep penetration.

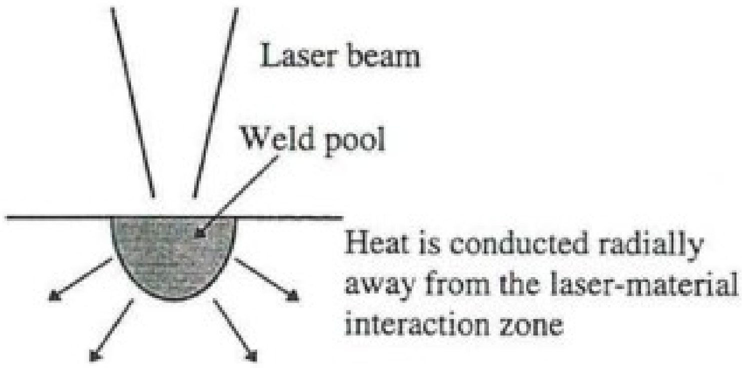


Figure 2 Conduction laser welding

B) KEY HOLE WELDING

The keyhole laser welding takes the form of a narrow, deep and vapour filled cavity bounded by liquid metal. As this zone is traversed across a metal sheet the liquid metal flows around the cavity and solidifies behind it.

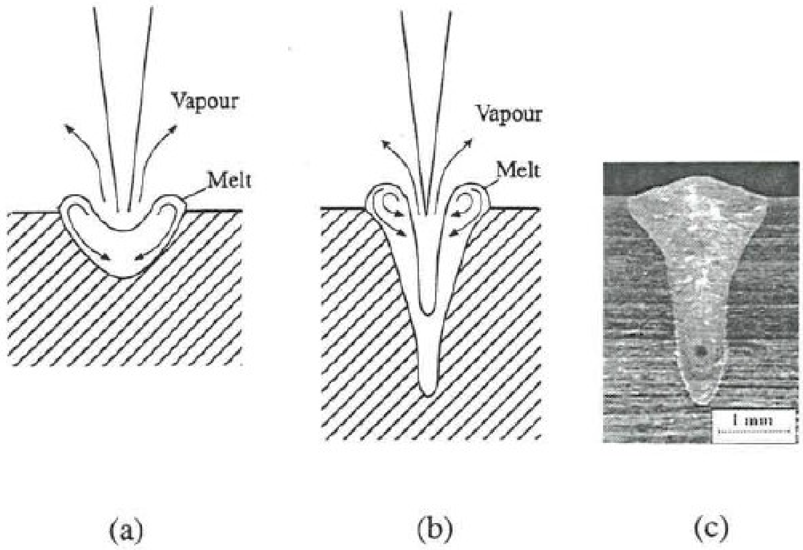


Figure 3 schematic diagram of keyhole depth while laser welding.

(a) At high power densities vaporization and thermocapillary stirring act together to create a dimple/pool in the centre of the metal (b) The dimple absorbs the laser energy more effectively and depends to create a keyhole (c) A typical micrograph of a keyhole.

1.2.3) POWER ABSORPTION IN DEEP PENETRATION KEYHOLE WELDING

The plasma associated with the keyhole laser welding absorbs some part of the laser light. The light which is absorbed by the plasma cloud overhead the keyhole is re-radiated in all directions and only a part of it reaches the workpiece surface material. Energy which is absorbed by the plasma inside the keyhole is finally re-radiated and conducted onto the keyhole flanks the melting procedure. The majority of the laser energy is absorbed straight by the walls of the keyhole as a result of Fresnel absorption can be observed.

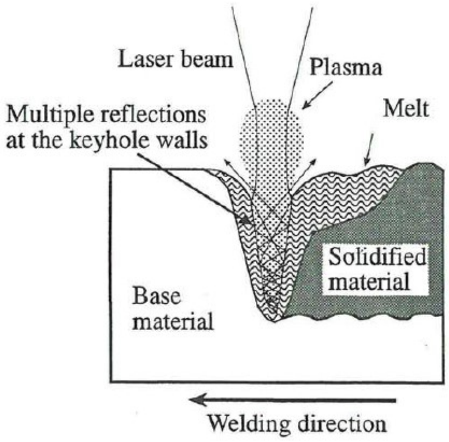


Figure 4 Schematic of the deep penetration laser welding process

1.3) LASER BEAM TYPES

THERE ARE DIFFERENT TYPES OF LASER USED IN WELDING ARE AS FOLLOWS:

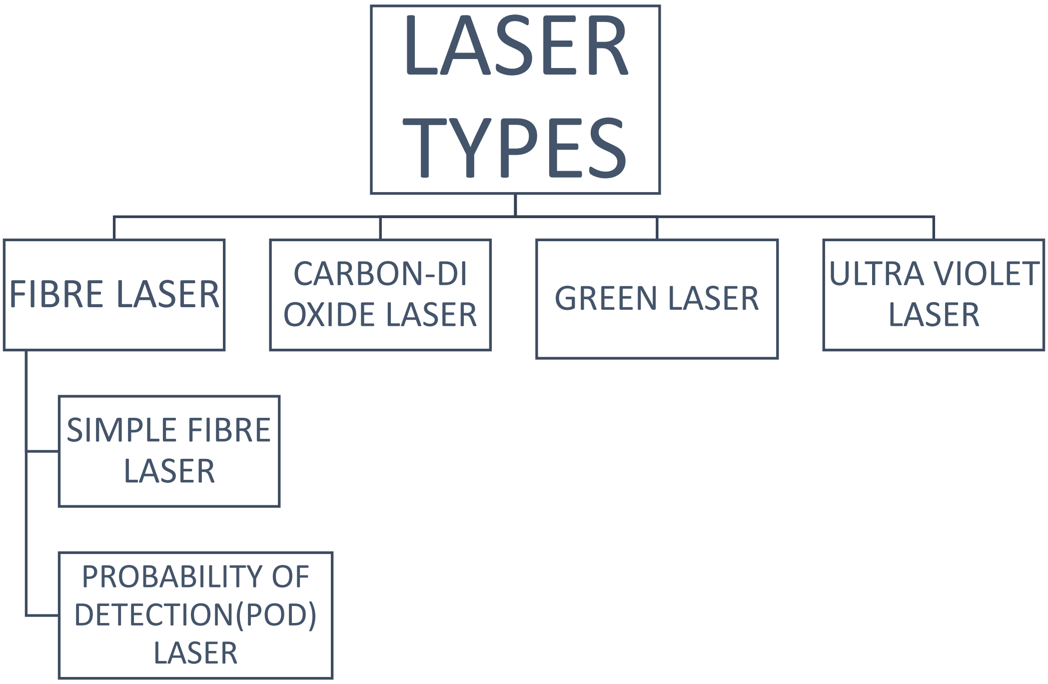


Figure 5 Types of laser beam

The fibre laser is classified in two different types as simple fibre & pod laser fibre. The simple fibre is used for laser welding in regular part but POD laser fibre is used when a colour welding is needed at the end a person can find the colour of weld is different. It can be blue, orange or yellow according to requirement. carbon-dioxide laser used when a large penetration is required to weld the material accordingly. while some of the material and more have high reflection, low absorptivity and high thermal conductivity so co2 laser is used. Green laser is used to weld copper it is the future of welding as we go in deep green laser is costly and can give more better results with best accuracy. Th UV laser is used to weld hard plastics and more likely in future we might see more progress in this too.

In laser welding there is different criteria as we move step by step as first is to identify the parameters of laser welding and it's is most difficult task itself as there is no correct or perfect formula to find that but we can use the iterative method to do so. There are different types of frequency intensity.

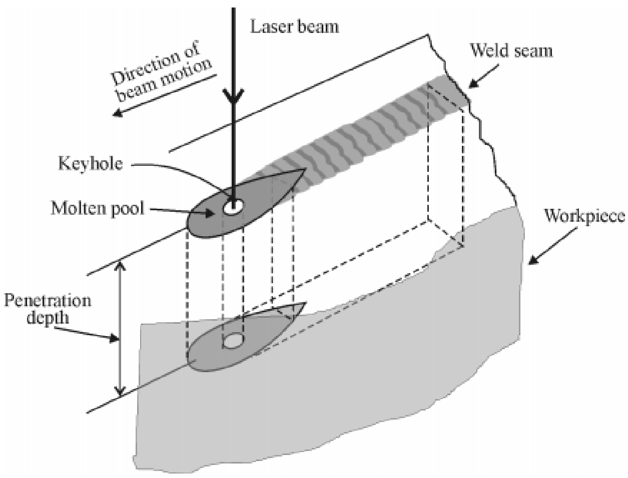


Figure 6 Schematic diagram for laser welding process

The peak portion shows the laser light prominent the surface, melting it and producing a liquid interface to move into the material. The centre part of **Figure** shows the surface beginning to vaporize. The vaporized material remains mostly un-ionized and transparent so that the light can still reach the surface.

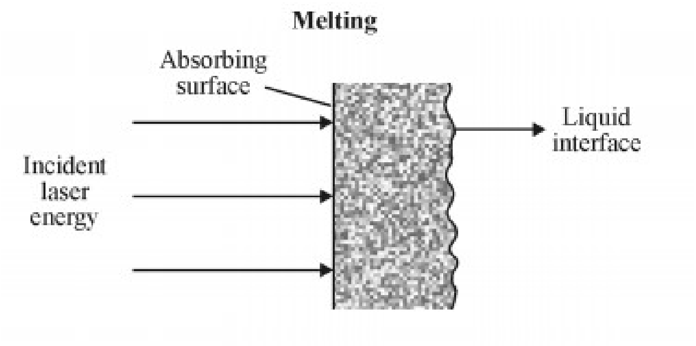


Figure 7 Schematic of melting material

The plasma shielding obviously can have undesirable consequences for a welding operation. It keeps the laser energy from reaching its intended target and can strongly reduce the amount of welding that can be performed.

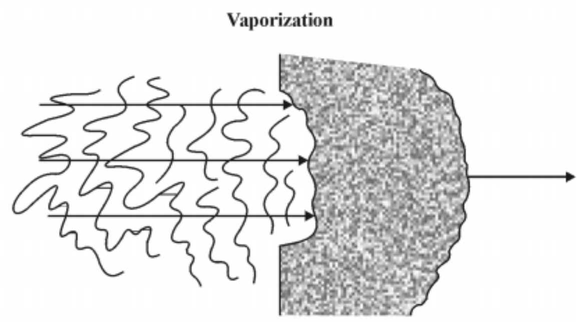


Figure 8 Vaporization of material

it is relatively easy to neutralize the effects of plasma shielding. One can limit the power in the laser beam and keep it under the level at which the plasma is sparked. Also, one can sweep the plasma away with a high velocity shielding gas. This will be described in the section Welding Procedures.

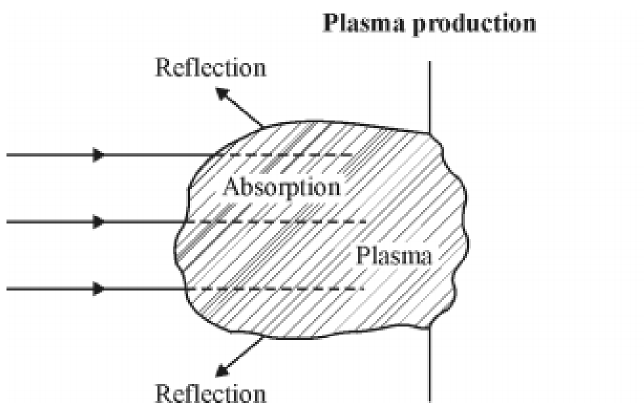


Figure 9 Plasma activity of absorption

1.4) THERMOCAPILLARY FLOW IN KEY HOLE LASER WELDING

The broadening of weld bend is due to thermocapillary flow. the laser is pointing at the top part of the weld but still don't give a explanation if broadening of the weld pool. The phenomenon can be described as three

1.4.1) Surface Tension Force

1.4.2) Buoyancy Force

1.4.3) Electromagnetic Force

1.4.1) SURFACE TENSION FORCE

The surface tightness of a melt declines with temperature. In the case of laser welding this means that the surface tension will be at a maximum at the edges of the weld pool and a minimum in the centre. This surface tightness gradient creates a stirring action which performance outwards from the centre of the weld pool

1.4.2) BUOYANCY FORCE

The density of liquid metals goes down with temperature. Thus, the hotter melt towards the centre of the weld pool will tend to rise whilst the cooler material at the edges will tend to sink. This action reinforces the surface tension stirring effect. This usually extends to the top of the weld profile to give it a different shape. this maximum expansion of the welding dam is stabilized by introducing improved thermal conductivity at the top of the weld pool.

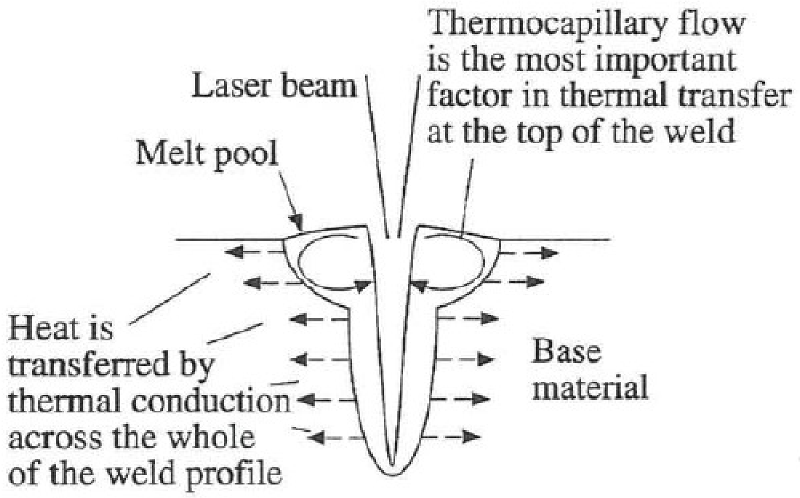


Figure 10 Buoyancy force schematic diagram

1.4.1) ELECTROMAGNETIC FORCE

The electromagnetic force can be neglected due to the fact that no electrical current is used.

2) LITERATURE REVIEW

2.1) FACTORS AFFECTING THE EFFICIENCY OF LASER WELDING.

- Power used in welding
- Power absorbed by the work piece but not used in melting.
- Power that never reached the work piece or reflected.

The rate of force involved in the melting process has increased with the welding speed and, more importantly, the aspect ratio of the cross-section of the weld has changed to provide the highest joining values. This increase in welding efficiency with increasing processing speed is the result of a decrease in the corresponding lateral motion in the melting. This reduction in movement occurs because, at higher speeds, the melting has a shorter lifespan of any single area in the weld line:

The three most important process parameters:

- The lens or mirror focal length.
- The laser power.
- The laser welding speed.

From the point of view of process efficiency, it is clear from our earlier discussion that the process speed should be set at the maximum possible value. This will generally entail the use of extreme laser power. This mixture will give the greatest connection rate and thinnest welds at the extreme welding competence.

2.2) THE INFLUENCE OF GAP WIDTH ON LASER WELDING.

The work demonstrates theory and testing that the process can be accepted and can be developed in small spaces. As the gap reaches a limited value however, the welding system collapses. Larger gaps can be accommodated if the geometry of the cut edges is suitably altered The gap between two material's should be removed using fixture or proper alignment, material thickness, focal diameter of the laser beam and focal length of the laser beam.

To reduce gap while welding

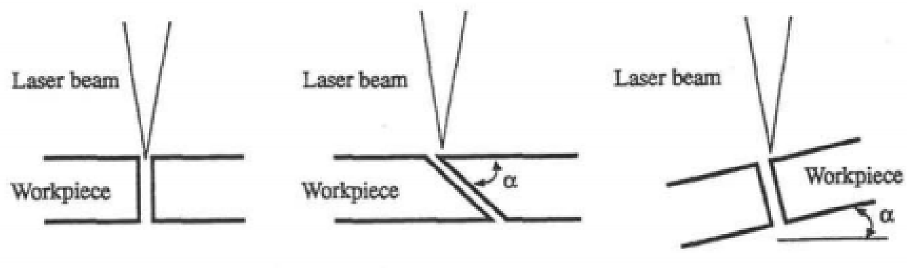


Figure 11 Gap reduction during welding

To avoid gaping between two similar or uncommon materials the position of work piece can be changed if we make work piece in a angle we might conclude that the gap is reduced but it depends on the material edge and its surface quality while welding. The best possible source to reduce the gap is to tilt the work piece in some angle greater than 15° and make other piece fixed on the edge this way we can reduce some gap.

2.3) A POINT AND LINE SOURCE ANALYSIS OF THE LASER MATERIAL INTERACTION IN HYPERBARIC KEYHOLE LASER WELDING.

The results of a theoretical and experimental research program that investigates laser welding at high pressures. In a test it was found that the welding method quickly collapsed from excessive air pressure if argon or nitrogen was used as a shield gas. In the case of helium however the depth of the welds decreased slightly as the pressure increased from 0.8 MPa. A theoretical model using the coupling point and the power line source was used to test the welding connection. The energy source represents the absorption of laser plum plasma above the key. The line source represents the energy absorption in the key hole. Both the experimental and theoretical results agreed that as the helium pressure increases the source of the points increases in size and the linear source decreases which means a gradual decrease in weld depth.

2.4) EFFECTS OF DIFFERENT SHIELDING GAS COMPOSITION ON THE PROCESS OF CW LASER WELDING IN THE HYPERBARIC RANGE.

the results of an investigation of laser welding with different shield gas mixtures at pressures above atmospheric. identified trends in weld pool geometry using helium at hyperbaric pressures and showed that the deep penetration welding process was not possible at these pressures when using argon or nitrogen as the shield gas. The present work concentrated on the effect of using mixtures of helium and argon. Once again, a combined line and point source energy transfer model was employed to analyse the results. The charge in proportion of the line and point sources was calculated for different atmospheres and pressures and this gave a close agreement with the experimental results.

2.5) AN ANALYTICAL THERMODYNAMIC MODEL OF LASER WELDING.

The previous model of deep welding - penetration laser has been simplified to provide a useful model for process analysis. This work involves the modeling of various energy absorption processes that determine the composition of the keyhole and thus the size of the molten pool. The depth of penetration and the weld width (top and bottom) determined by the model is shown to be very consistent with the test results. The expansion of the top of the weld seam due to the flow of Marangoni is precisely followed by introducing an artificial amount of heat transfer workpiece to the top of the weld. The model allows for the analysis of the weld profile dependence on process parameters.

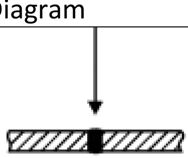
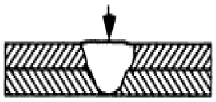
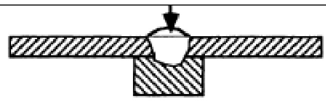
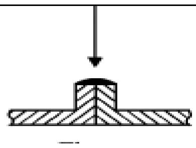
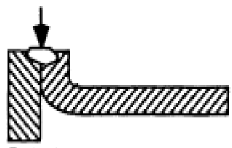
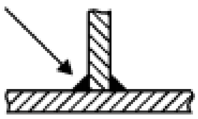
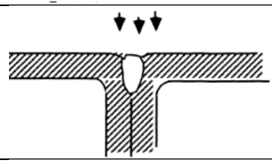
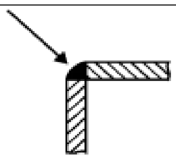
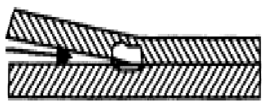
2.6) LASER WELDING OF ALUMINUM TO ALUMINUM.

Laser welding aluminum to aluminum components is technically and commercially feasible. Laser-interface misalignment must be optimised to produce a complete weld without excessive dilution of the melt with copper. Thermocapillary is responsible for the lateral spread of the stainless-steel melt and the eventual contact melting of the copper. Argon/Air is the preferred weld shroud gas. Helium does not ionise sufficiently in the plasma above the weld and hence aids the production of a narrow weld with insufficient Marangoni flow. Nitrogen may increase the susceptibility to solidification cracking in laser welding of austenitic stainless steels as it suppresses the formation of delta ferrite.

2.7) THE EFFECT OF PROCESS SPEED ON ENERGY REDISTRIBUTION IN DEEP PENETRATION FIBRE LASER WELDING.

Fresnel absorption at the walls of the keyhole is the dominant energy transfer mechanism in laser welding. Energy absorption by this method is optimised when the keyhole walls are close to the Brewster angle with respect to the incident beam. As speeds upsurge the pit wall will become more inclined and engagement will be concentrated. Plasma absorption plays a more minor role which diminishes in importance as welding speeds are increased. An increasing amount of incident power is lost to the welding process as speeds are increased. Although plasma plume absorption decreases with speed this is more than compensated for by increases in workpiece surface and keyhole reflection effects.

Table 1 Types of welding position

Name	Diagram	Name	Diagram
Butt joint		Fillet/lap joint	
Spot/Lap weld		Spike/Spot weld	
Flange joint		Edge joint	
T-joint		Flare weld	
Corner		flare weld or kissing weld	

2.8) MATERIAL USED FOR ALUMINUM 6063-T6.

Table 2 Components of Aluminum 6063 -T6

Element	AL 6063 % Present
Si(silicon)	0.2 to 0.6
Fe(iron)	0.0 to 0.35
Cu(copper)	0.0 to 0.1
Mn(manganese)	0.0 to 0.1
Mg(magnesium)	0.45 to 0.9
Zn(zinc)	0.0 to 0.1
Ti(titanium)	0.0 to 0.1
Cr(chromium)	0.1 max

3) THEORETICAL CALCULATION OF ALUMINUM 6063 T6

3.1) POWER USED IN MELTING FOR ALUMINUM 6063 T6

NOMECLATURE VALUE

P(k)= Power involved in melting material.

A = Weld cross section area (m^2) = (36*5) mm= 180 *10^-6 m^2

v = Welding speed (m/s). 1100 m/s

p = Density (kg/m3) = 2690 (kg/m3)

Cp = Heat capacity of solid (K). = 900K

(ΔT) = Difference between the average weld melt temperature and the room temperature (K).= [654+273-30-273]

L(f) = Latent heat of fusion (kJ/kg) = 3.9 x 10^5 (J / kg)

P(k) = A*v*P*[Cp* (ΔT) +L(f)] ________ (1)

= (36 X 5 X 10^-6) * 2700 * 1100 * [900 * (654+273-30-273) + (3.9*10^5)]

= 1672 watts

= 1.6kw

3.2) DEPTH OF PENETRATION OF HEAT ENERGY INTO MATERIAL TIME

D = the depth of penetration of the heat (CM)

k = thermal diffusivity of the material (cm^2/sec) = 0.097 (cm^2/sec)

t= time in sec = (1100 mm/min) = 18.33 (mm/sec)

D = SQRT(4*k*t) ___________________ (2)

= SQRT (6.78)

= 2.67 mm depth nearly.

4) MACHINE CONFIGURATIONS

The machine which was used in Fibre laser welding machine called PRIME. The machine was capable of performing at high speed and used in R & D development. Fibre-laser machine was used with air gas for aluminum alloy welding. The machine is 3 Axis (x, y and z). The capacity of machine was 3kw.

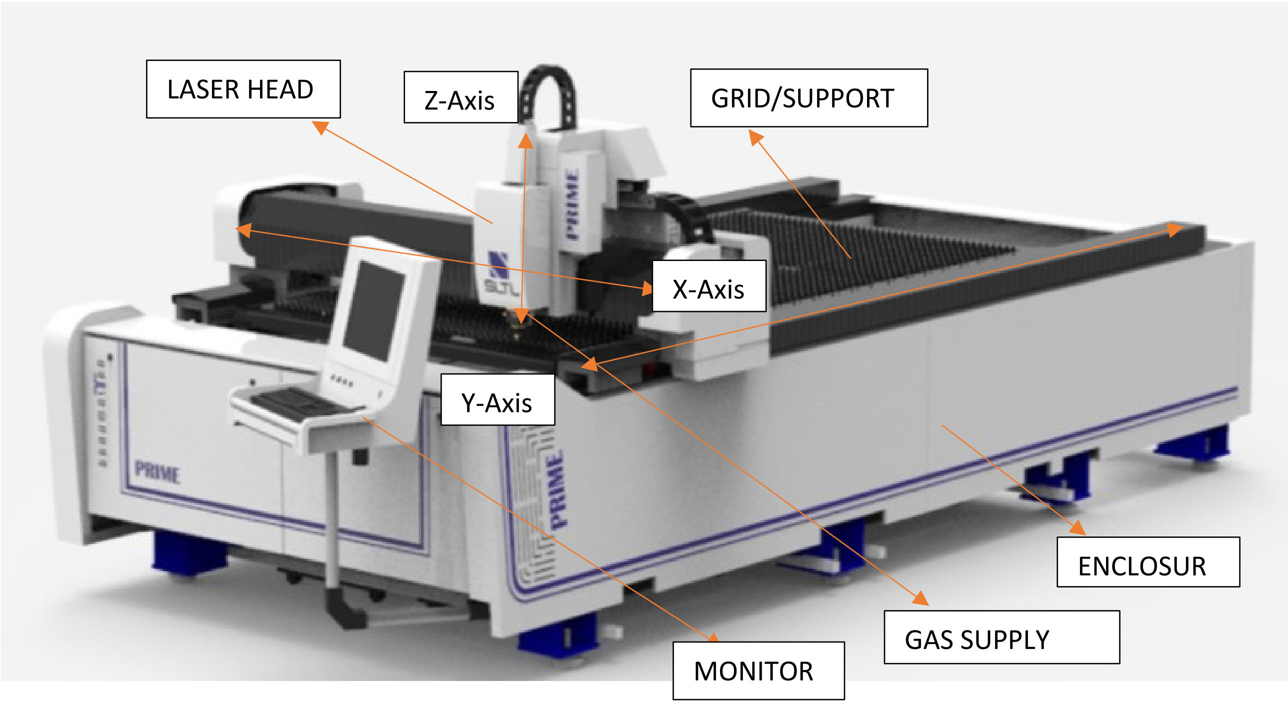


Figure 12 Laser welding machine diagram

4.1) SOFTWARE PROCESS FOR LASER WELDING.

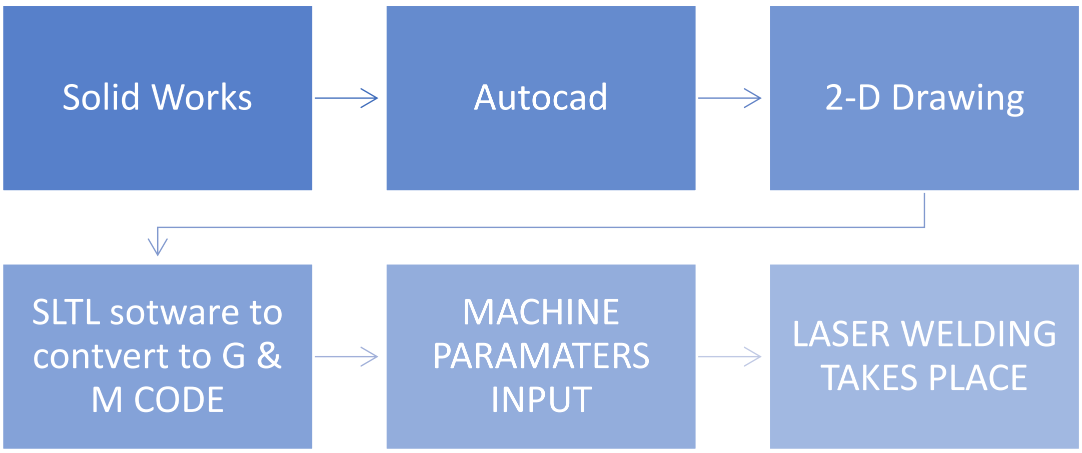


Figure 13 Software working flow diagram

5) LITHIUM- ION BATTERY SINGLE CELL DEMO

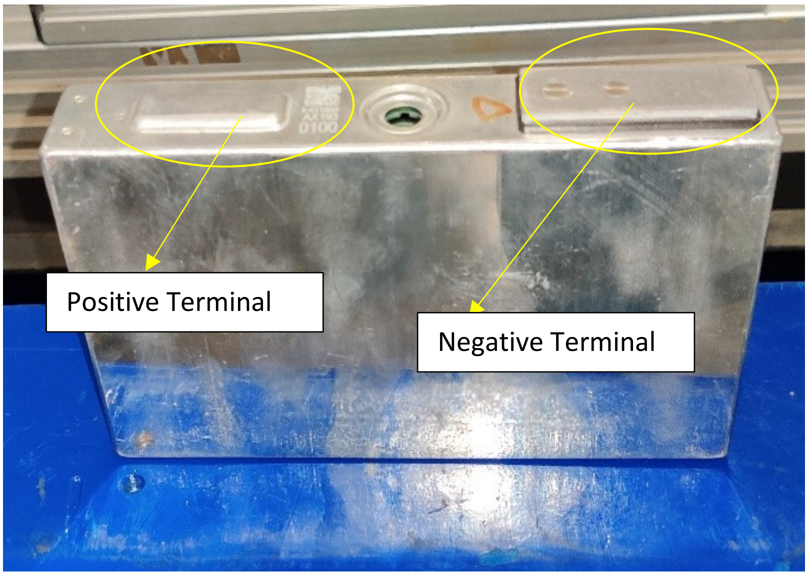
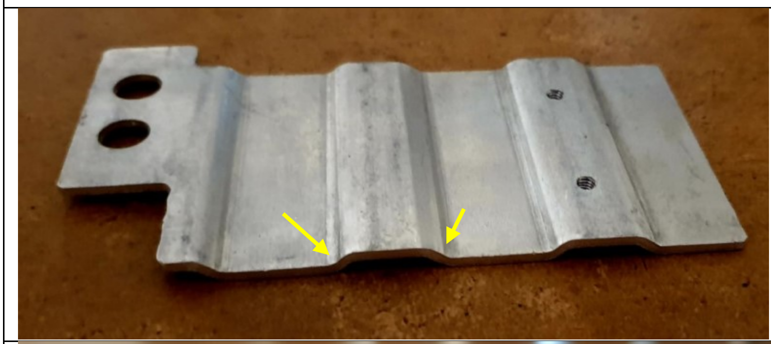


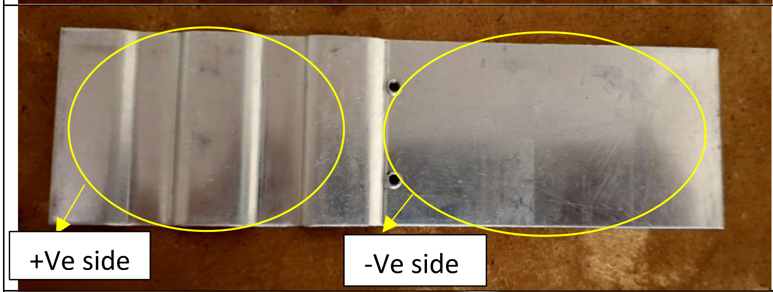
Figure 14 Lithium-ion battery mono unit cell

Both the terminals are 1.5mm depth and then for safety plastic is placed. The battery is minimum charged and 22 of placed in one box then sealed together. The battery is connected in series. To make connection in parallel al plate was developed by SLTL team. The plate is kept in such a way that it connects all 22 cell or module together in parallel. The plate design to do this task are mentioned in below table with its necessary description.

5.1) PLATE FOR LASER WELDING WITH LITHIUM-ION BATTERY.

Table 3 AL plate description

IMAGE	DISCRIPTION
	As shown in left the plate is aluminum 6063. Its thickness is 1.5mm and bending is provided to maintain the gap between terminals. The plate is used for positive terminals.
	Side view of above description plate.

	The plate shown in left diagram is made of aluminum 6063 material. Its thickness is 1.5mm and used to weld negative terminals at the end of ion lithium battery.
	There are 5 plates set up for each battery to connect. The thickness is 1.5 mm and left side with bending is positive terminal and right-side negative terminal.
	Side view of above description plate.

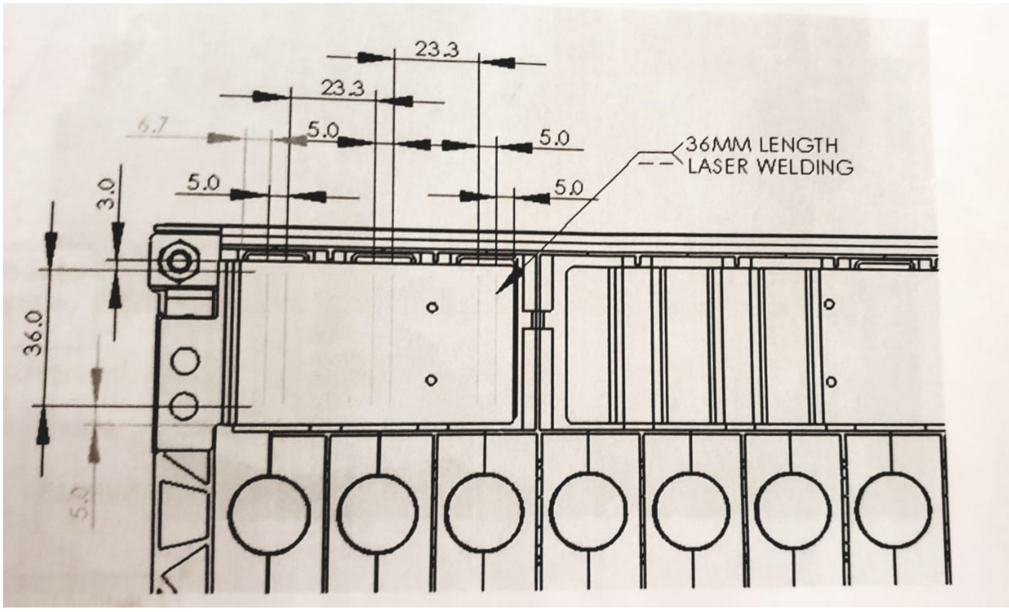


Figure 15 Welding lines schematic diagram on battery.

As shown in the above image weld lines are displayed on 2-d drawing of lithium-ion battery. There Is a particular place to weld the material with battery. If material weld alignment is not according to the above diagram, then battery might get damaged or rejected.

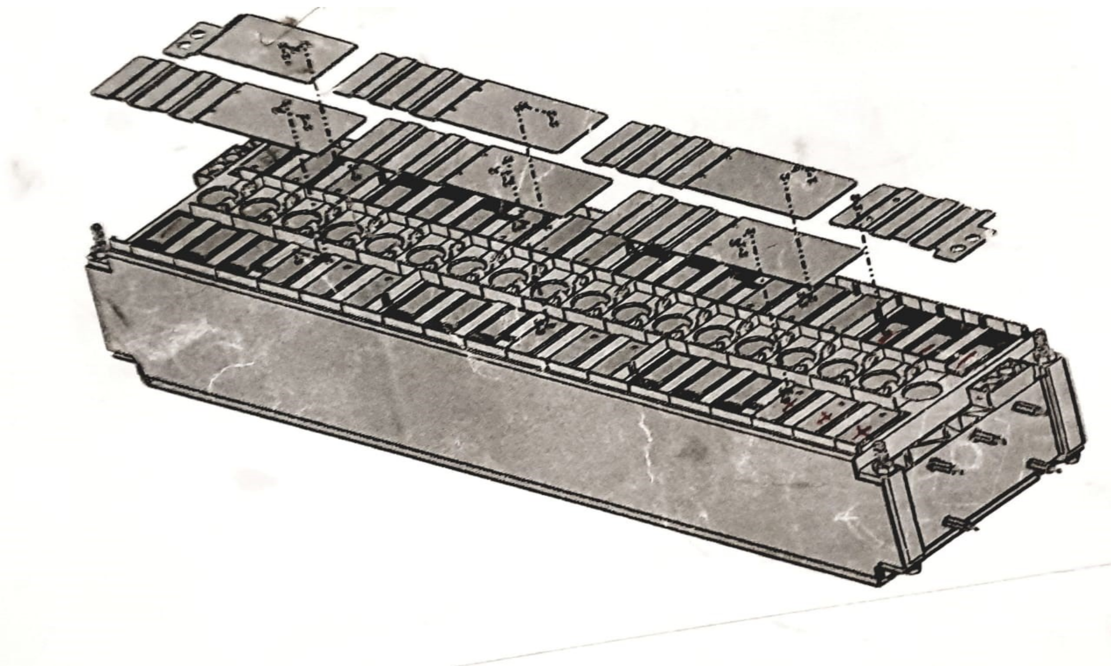


Figure 16 lithium ion battery with welding schematic plate

The above image represents the lithium-ion battery with alignment of plates on the top of battery. First battery was placed inside the fixture and then the plates were kept on the top of the terminal according to the above image. As the plate is placed as per the location given the fixture covers the plate from the top and tight grip was provided so no gap is found when welding takes place. Now the laser weld starts slowly as per the parameters one can obtain the weld as required with efficiency.

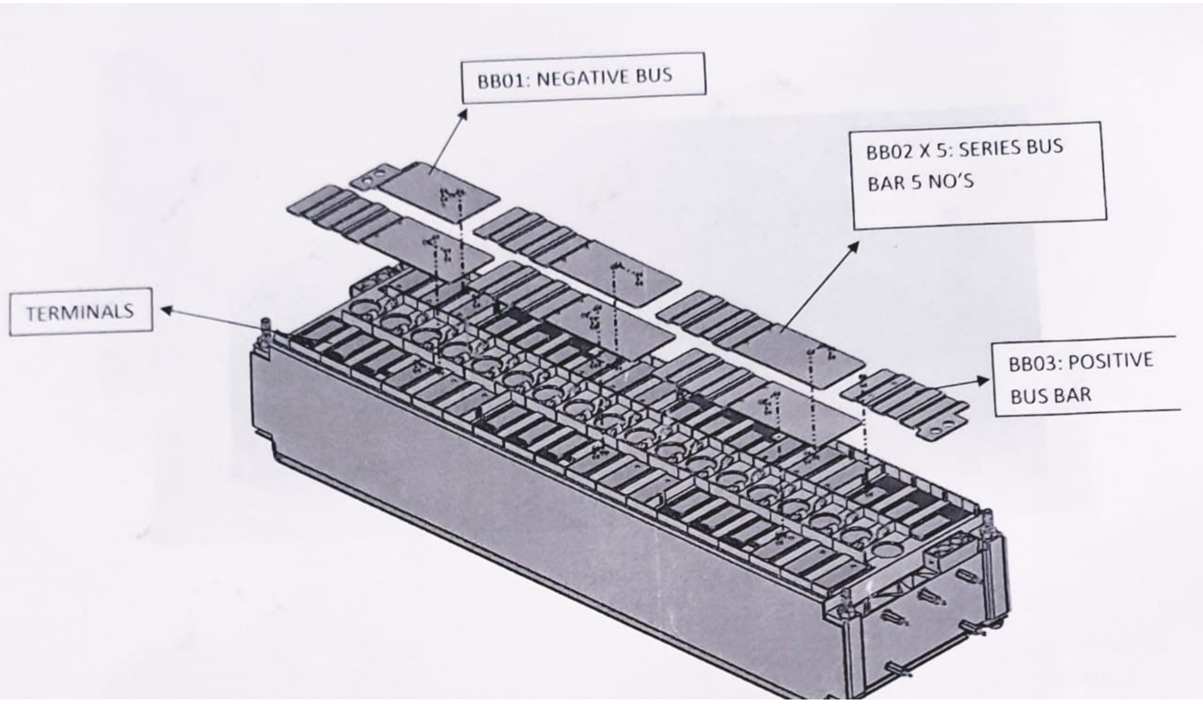


Figure 17 lithium-ion battery

6) RESULTS ON SAMPLE

Material: AL 6063; defocused beam (255); frequency 10000(HZ);

Table 4 Results on sample

Sr No.	Duty cycle (%)	laser power (watt)	Feed speed (mm/min)	Accepted/Rejected	Description
1	85	3000	1100	Rejected	Penetration was more than required (3 mm)
2	85	1900	1100	Rejected	Penetration was more than required
3	85	1800	1100	Rejected	not melted, still last deep hole was found
4	85	1700	1100	Rejected	weld was not penetrated till back side
5	85 100	1600 800	1100 2500	Accepted	weld was better than previous parameter as at the end hole depth was reduced

Duty cycle mean the percentage of actual power provide and used power for laser welding. Based on the theoretical calculation we can find that practical done development both matches nearly the same. Based on this one can select the final parameters for laser welding the lithium-ion battery. As we can observe from 1 to 4 a linear pattern was observed but at the 5^{th} row one can observe that there are two laser power with two different speed for better understating lets compare 4^{th} and 5^{th}.

As shown the power used for 4^{th} weld was same for 36mm length weld so we found a hole at the end of the weld. This hole is not acceptable so we dived the length with two power supply for first till 32mm we used 1600 wats but for the last 4mm we used 2500 watts to remove that hole depth.

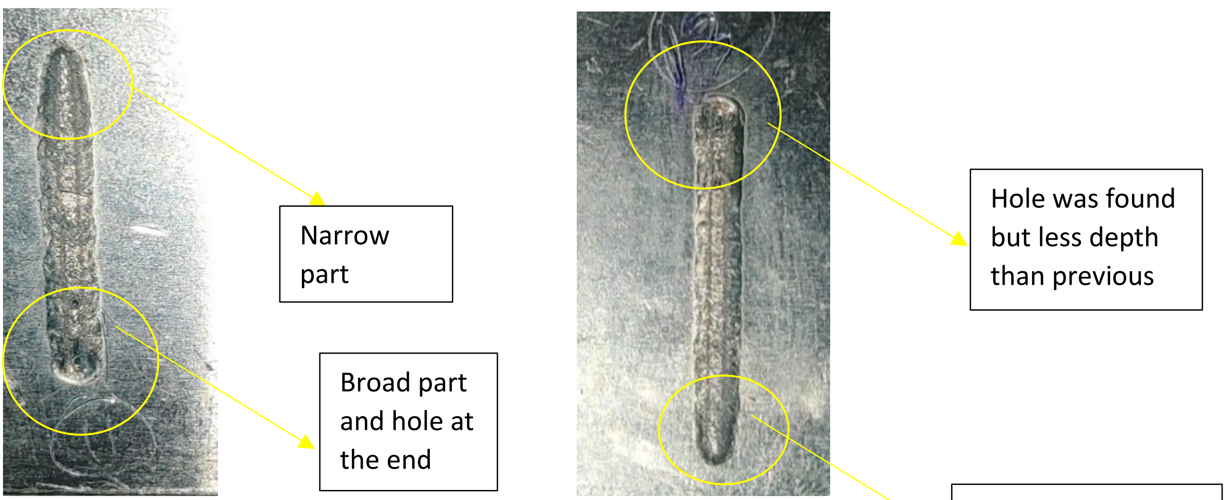


Figure 18 Showing comparison of 4th & 5th Sr no. welding power to eliminate the defect

6.1) ACCEPTABLE PARAMETERS USED FOR LASER WELDING

Laser Power: 1600 Watts

Welding speed: 1100- mm/min

Focusing mirror focal length: de-focused 255 mm

Shielding gas: air

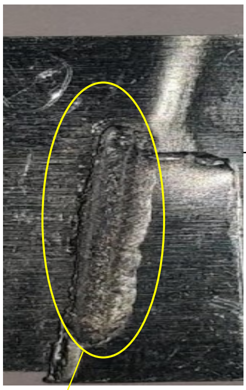
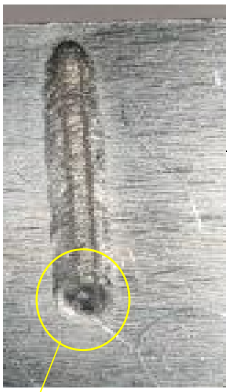
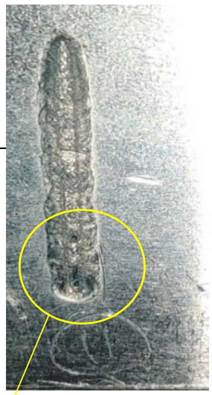
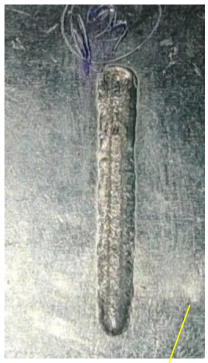
Work piece material: Aluminum 6063 T6 (1.5mm thick)

Gap width: Bead on plate - 0.001 (negligible)

6.2) DISCUSSION ON WELDED SAMPLE

The material was arranged by company it took 15 to 10 days to find the correct material for laser welding that material was cut down into pieces of 100 X 50 mm in a rectangular shape. Two plates of each 1.5 mm were joined together we also maintained that there is no gap between both the plate the welding was of spot weld or lamp weld. In the below table some images of top view and back view showing the progress of iterative method that we have gone through during this process. The frequency was sent 10000 Hz and the speed was 1100 (mm/minute). the laser pointer was seton 255 mm above this material to make weld properly

Table 5 Top view of laser welded material

Laser power (watts)	3000	1900	1800	1700	1600
Top view					
	(a)	(b)	(c)	(d)	(e)

Weld pattern is faded

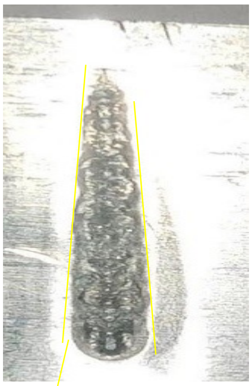
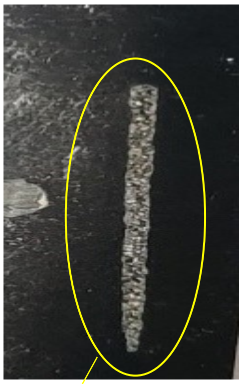
Decreasing order patter

Deep hole found at end

hole found at end

Perfect weld

Table 6 back view of welded samples

Laser power (watts)	3000	1900	1800	1700	1600
back view					
	(a)	(b)	(c)	(d)	(e)

- (a) Weld bend in decreasing order
- (b) Weld faded at end
- (c) Faded weld
- (d) Compare to other better
- (e) Perfect weld bend.

As shown in the above image the laser power is from 3000 Watts to 1600 Watts. the top view of welded sample is presented.

- As shown in figure (a) where 3000-watt laser power has used the penetration of laser weld was more than 3mm. As we can see in the image the welded line is a spreader and not welded properly. We need to keep in mind while laser welding the penetration should not cross 2.8 mm.
- As shown in figure(b) we used 1900 watts power and at the end, you can see a linear pattern is formed from ascending order to descending order in a narrow pattern so again this penetration was more than 3 mm so the material was rejected. As we are doing laser welding with a lithium-ion battery the void should not enter more than 3 mm if that enters more than 3 mm the liquid inside the battery will come out and the hole battery will be damage.
- As we can see in image (c) see where 1800 was used. A perfect linear pattern is observed here but at the starting point of the wild hole was found and this hole was not a good option for laser welding on a lithium-ion battery.
- As we can see in image (d) the hole at the ending point was reduced and also a linear pattern has formed the penetration of welded material also exceeds 3mm but this was quite less compared to the others.
- As shown in the image (e) these are fully perfect parameters for laser welding. Where we can observe the void was not found and at the end, a bubble was found but the bubble did not bust so it’s good to go with this parameter.

6.3) COMPLETE AND INCOMPLETE PENETRATION IN WELDING

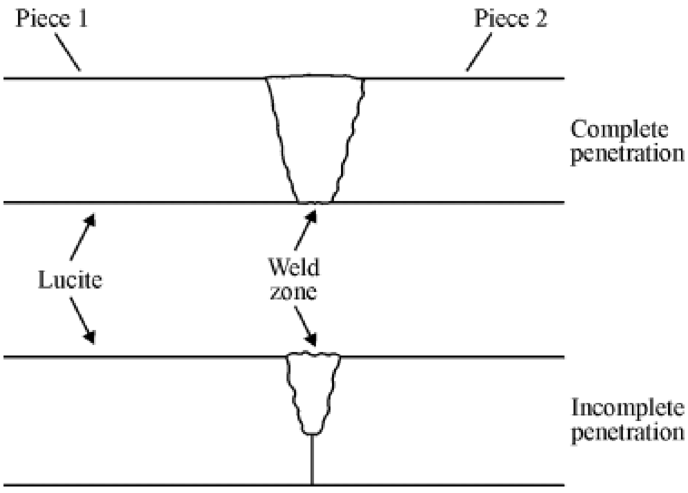


Figure 19 Complete/incomplete penetration in welding

Power absorption in deep penetration keyhole welding Majority of laser is absorbed by the surface of the keyhole which is absorbed directly. The process is called Fresnel absorption. In Fresnel absorption, some amount of laser beam is reflected from the surface of the wall. The absorption coefficient is dependent on the angle between the incoming laser and the key wall.

6.4) DEPTH VS POWER GRAPH BASED ON FEW CONVENTIONS

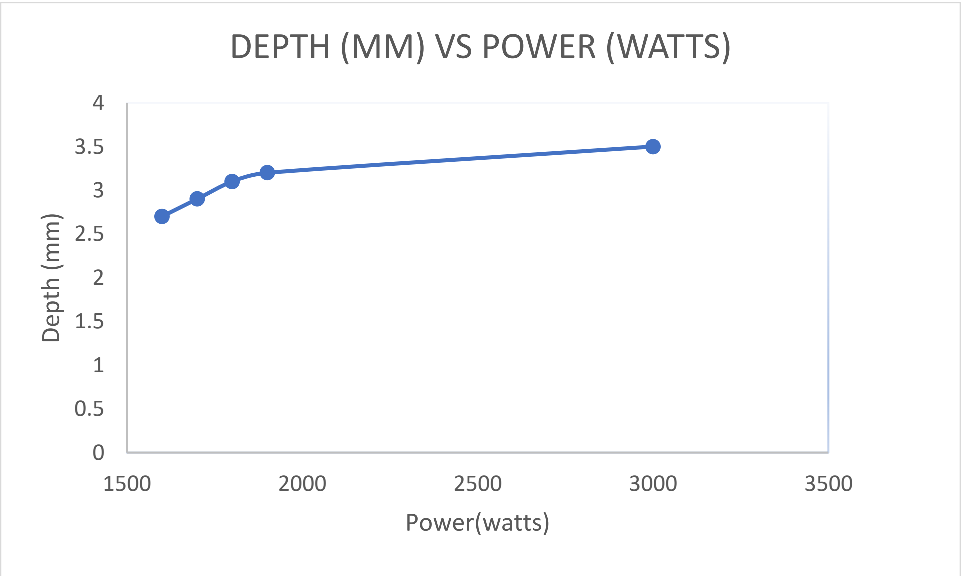


Figure 20 Depth vs Power

As shown in the above image of the graph represent depth versus powers used in laser welding. Keeping speed at a constant 1100 (mm/min). We can observe in the graph as the power is increasing the depth of penetration in material Aluminum is also increasing. However, the depth of material welded depends on various aspects but Other keeping aspects constant and watching on the power we can conclude that when power increases the depth of penetration increases in AL material of laser welded.

7) FISHBONE DIAGRAM

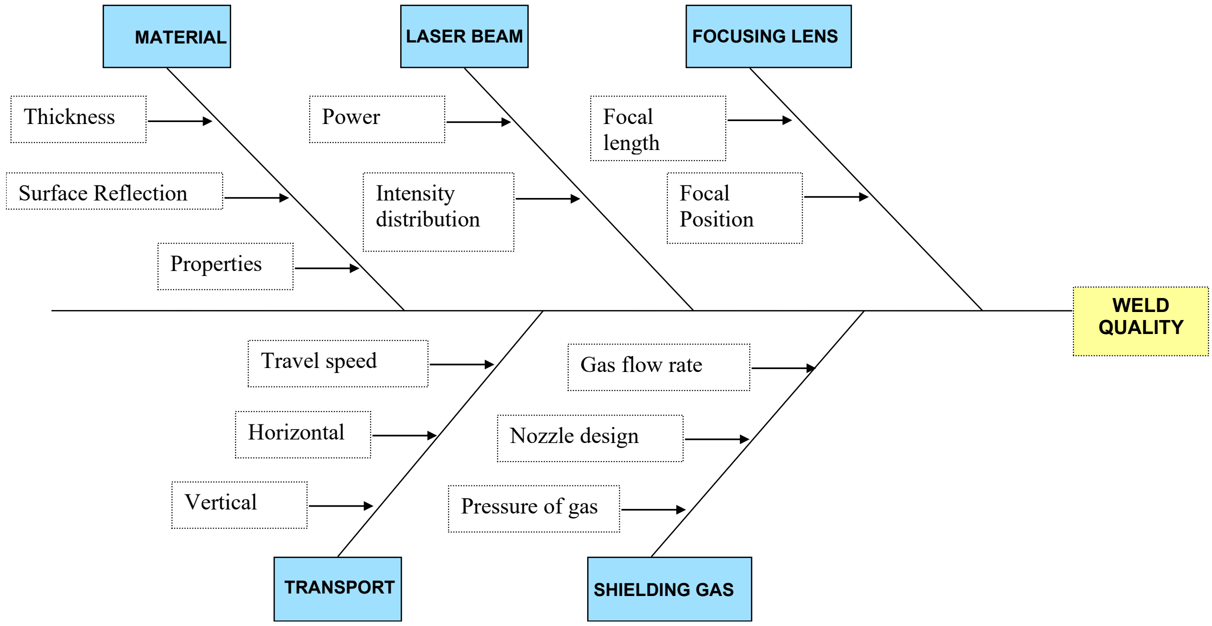


Figure 21 fishbone diagram of laser welding

fishbone diagram was initially created by Ishikawa. it is also known as the Ishikawa diagram. Common uses of fishbone diagrams are product design and quality defect prevention to identify potential factors causing and overall effect.

- In this fishbone diagram, we are discussing the weld quality of laser welded material. including material, laser beam, focusing lens, transport, and shielding gas. One needs to keep in mind this factor while laser welding thickness, surface reflection, and its properties included in the material.
- Shielding gas plays an important role in nozzle design gas flow rate and pressure of the gas while the material is welded. Transport is a major aspect while welding the travel speed of the machine in the x y direction including the Z direction and its position in the horizontal or vertical direction.

8) INTRODUCTION TO ELECTRON BACKSCATTER DIFFRACTION (EBSD)

An electron backscattered diffraction is a surface analysis technique. a technique to measure the crystalline materials. The electron backscatter diffraction the microstructure of its main importance to find the grain size structure, identification and grain boundary characteristic it also includes the properties like strength and hardness ductility corrosion electrical conductivity these all are the objectives of the EBSD. The crystalline nature of the material can be crystalline polycrystalline and amorphous. An online simulation for rum for similar alloy aluminum 6063 using software Aztec.

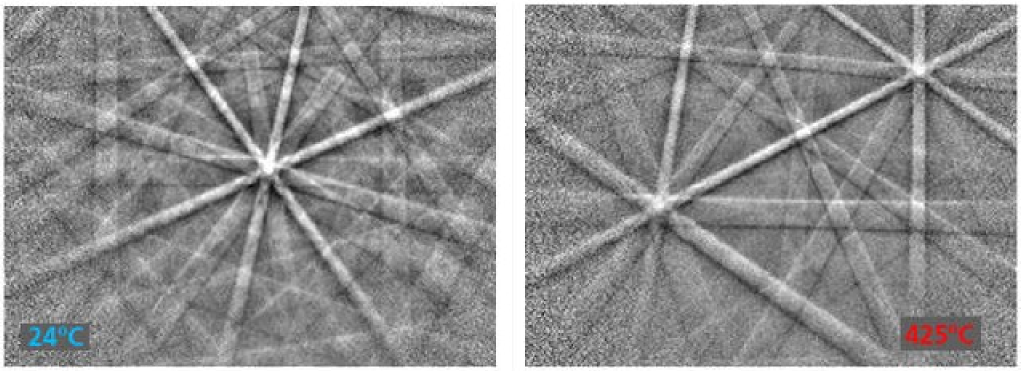


Figure 22 Typical EBSD patterns at 24ºC (left) and 425º C (right).

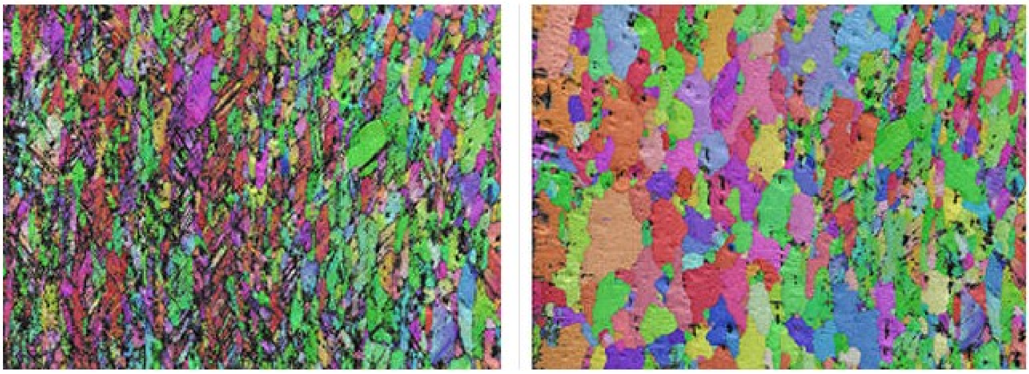


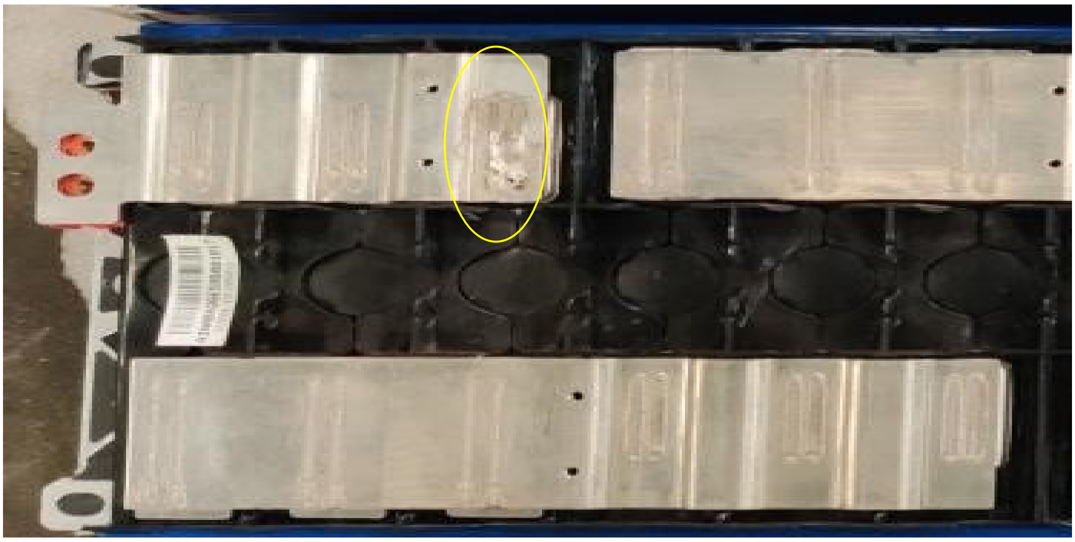
Figure 23 EBSD pattern IPF colored maps before (left) and after (right) heating to 440ºC.

The propensity of Goss and rotated Goss grains to resist recrystallization, as well as their nucleation in the early stages of recrystallization, has been noted. Rotated cube grain nucleation and higher growth rates result in the formation of dominant rotated cube texture in the tensile region of the bent sample.

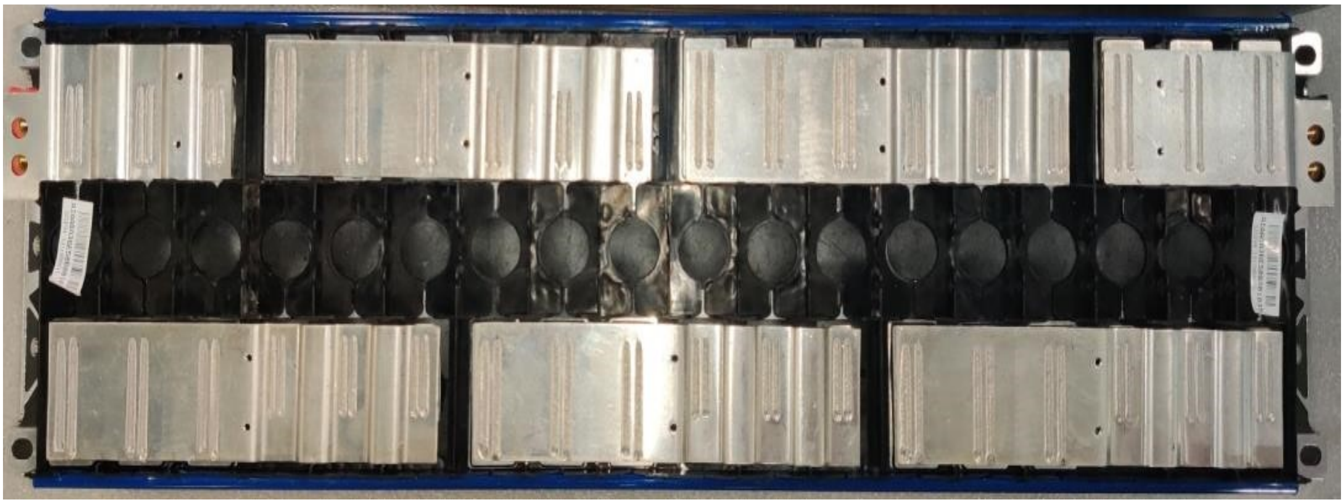
9) RESULTS OF WELDED ON BATTERY.

Table 7 result & discussion of laser welded plates on lithium-ion battery.

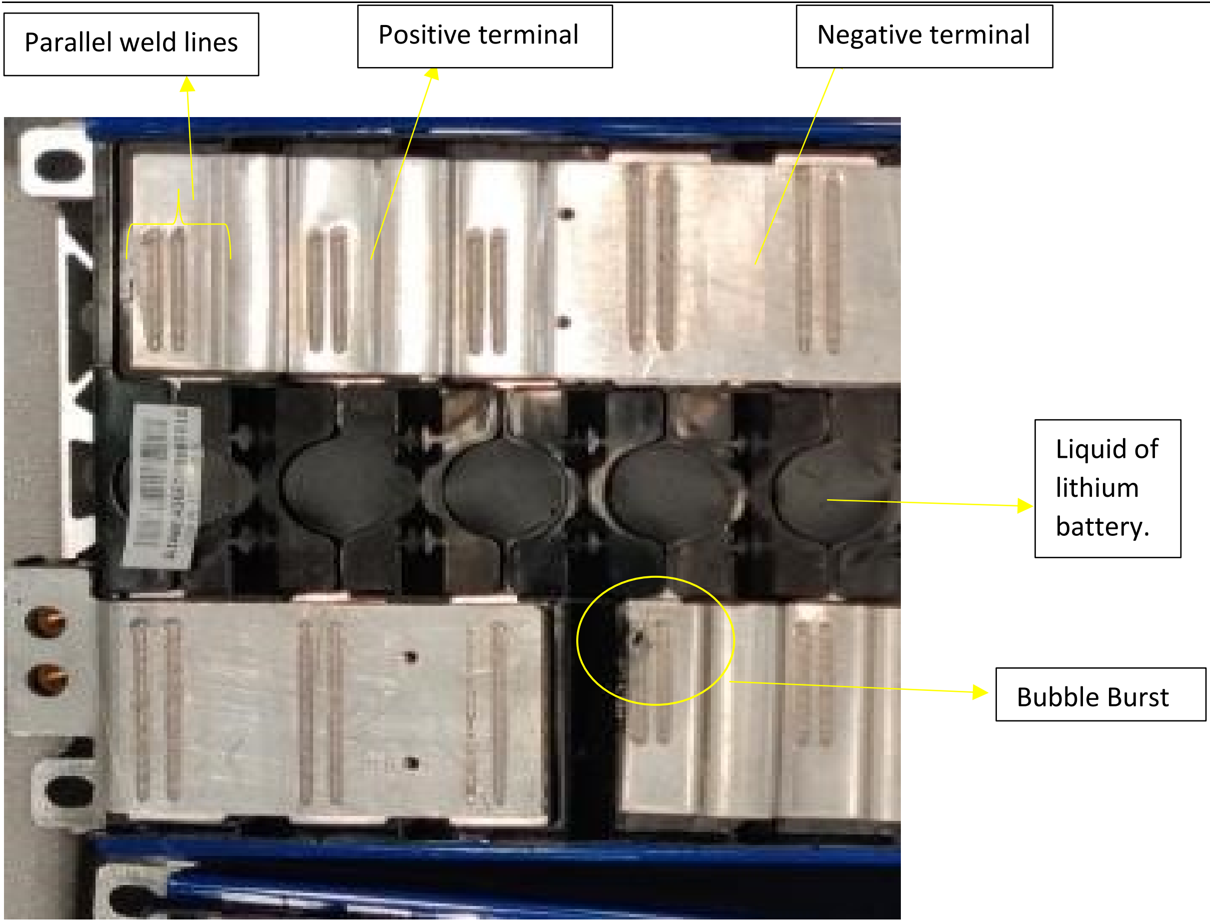
SLTL Sr No.	Total Voltage	Remark
1	21.05	All weld line is according to parameters applied but in the 3rd line a bubble was burst so the liquid from the battery pop-out. It caused minor damage to battery voltage. Al paste was applied to that place to stop the voltage loss from battery.



SLTL Sr No.	Total Voltage	Remark
2	21.85	All battery weld is perfect and no damage is observed.



SLTL Sr No.	Total Voltage	Remark
3	22.05	1 bubble burst was found on rest all good, at the end aluminum paste was applied to stop liquid flow from battery.



SLTL Sr No.	Total Voltage	Remark
4	22.06	Perfect welded with negligible defects present as no leakage was found.

10) ANSYS SIMULATION FOR LINEAR LASER WELDING.

Showing the linear laser welding takes place in an actual situation. This is a simulation done in ANSYS software and shows the motion of heating of material before it melts. In the below image, two major aspects are covered as time & temperature. Time moves from 0 to 0.35 sec and temperature distribution shows the heat-affected zone. The red place shows the most heated area and the blue zone shows the most cooled area. The laser moves from left to right direction in a linear way. the temperature varies from 2.5 x 10^3 to 3 x 10^2 K.

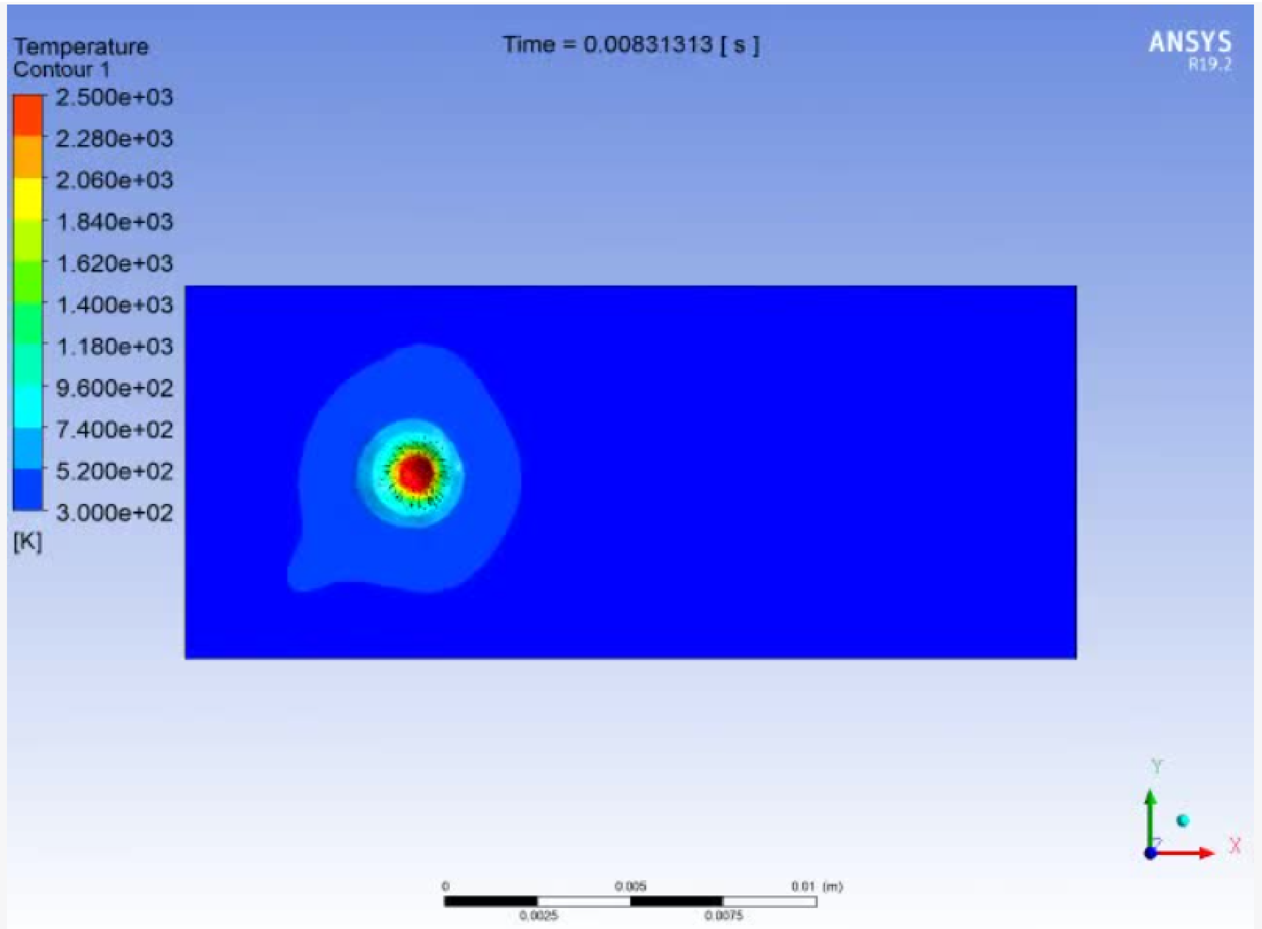


Figure 24 Starting point of linear welding simulation using Ansys how the material is heated and what effect that has on other surrounded parts

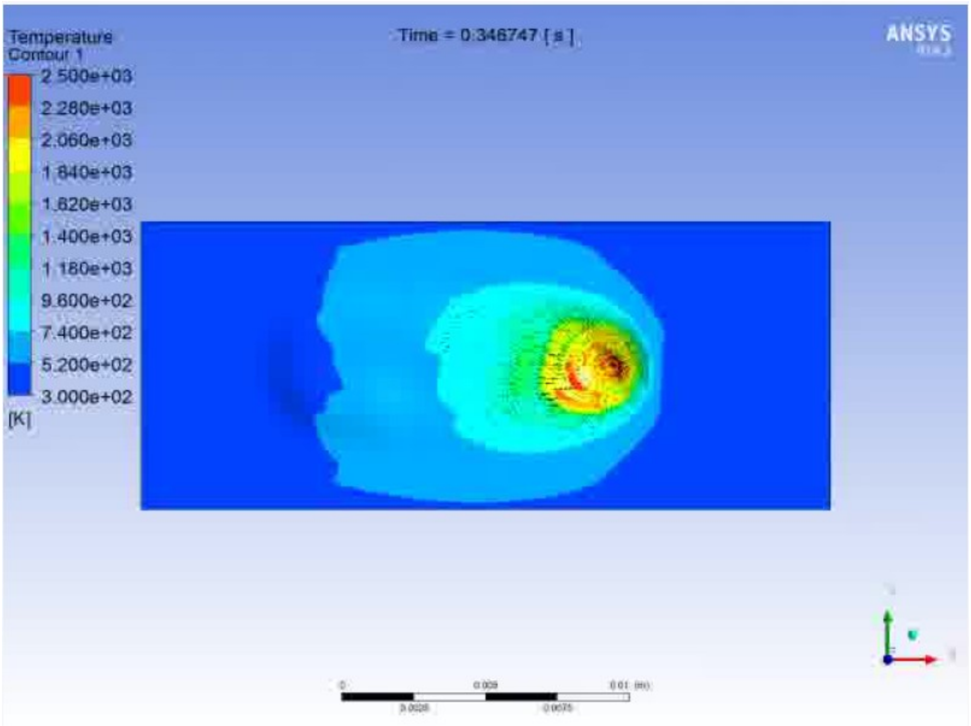
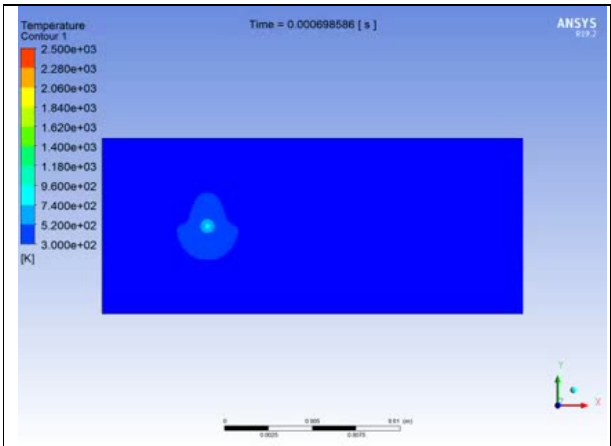
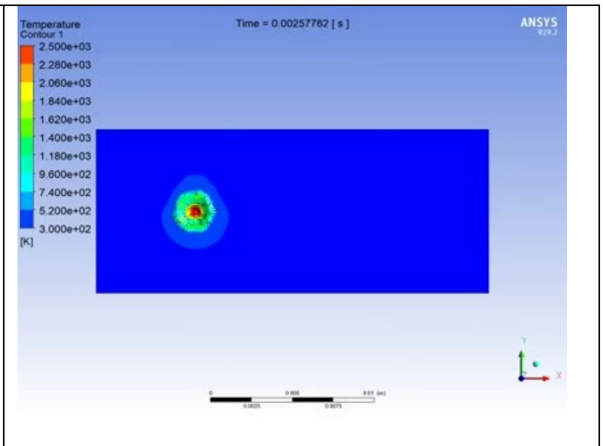
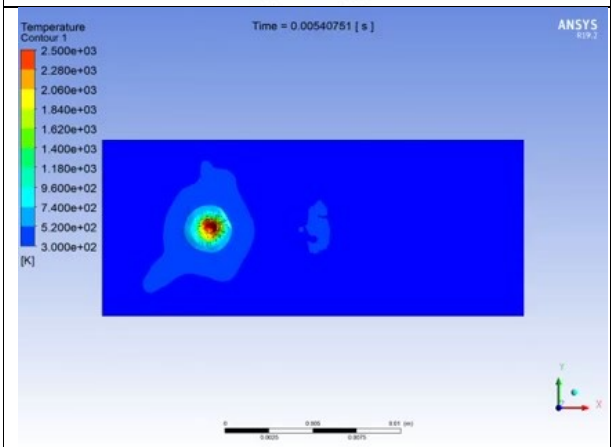


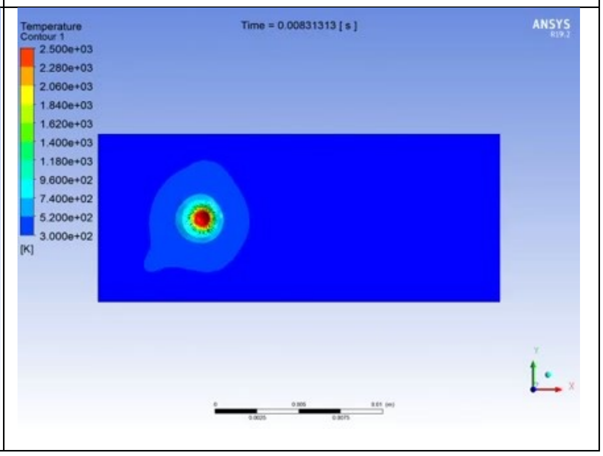
Figure 25 Final point of linear welding simulation using Ansys showing how the material is heated and what effect that has on other surrounded parts

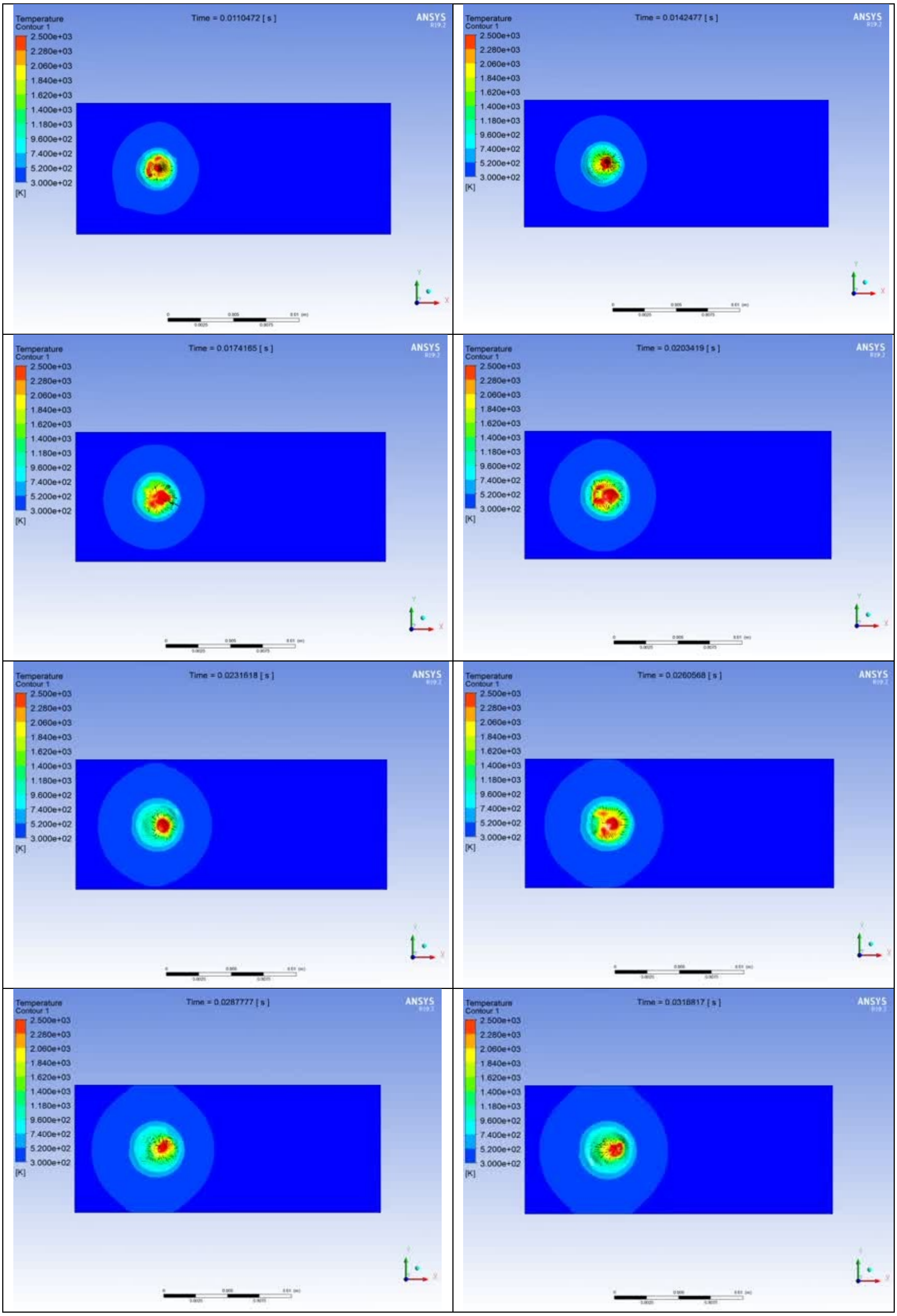
Table 8 Linear pattern of laser welding in 2-d using ANSYS showing heat affected zone with references to time










Temperature
Contour 1
2.500e+03
2.280e+03
2.060e+03
1.840e+03
1.620e+03
1.400e+03
1.180e+03
9.600e+02
7.400e+02
5.200e+02
3.000e+02
[K]
Time = 0.0110472 [s]
ANSYS
Time = 0.0142477 [s]
Time = 0.0174165 [s]
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Time = 0.0231618 [s]
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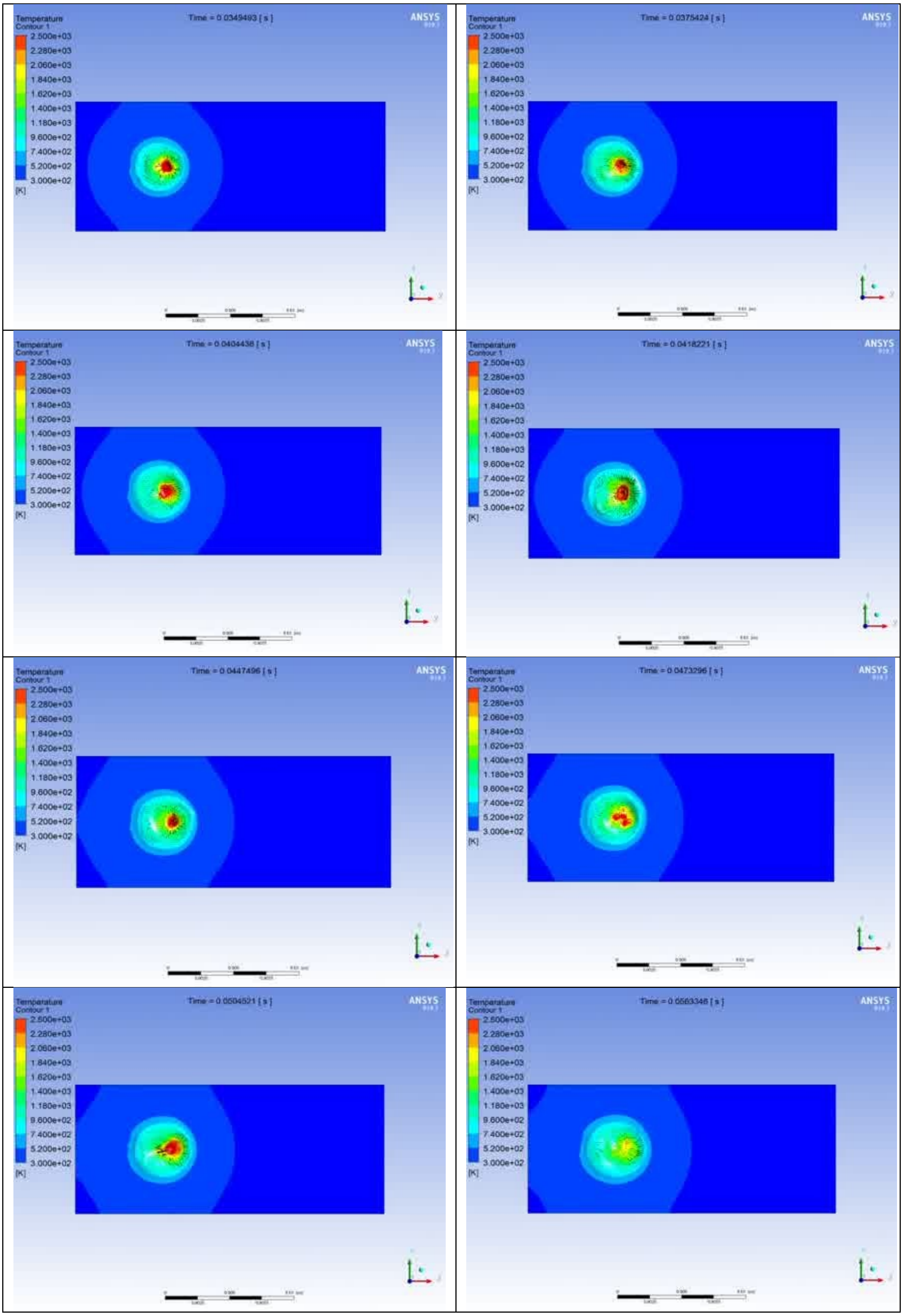
Time = 0.0318817 [s]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7.400e+02
5.200e+02
3.000e+02
[K]
Temperature
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ANSYS
Temperature
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Time = 0.0404438 [s]
ANSYS
Temperature
Contour 1
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ANSYS
Temperature
Contour 1
Time = 0.0447496 [s]
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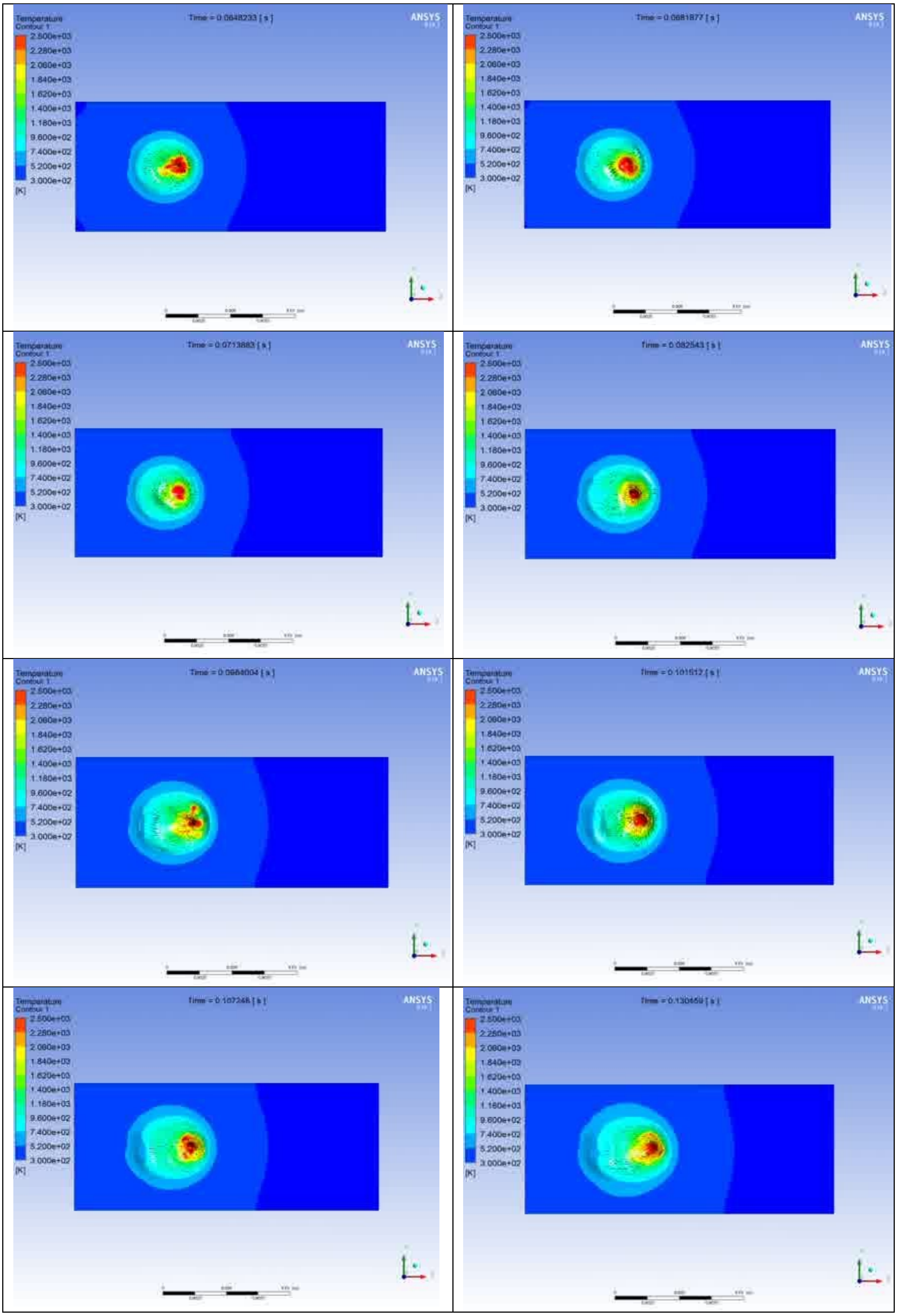
ANSYS
Temperature
Contour 1
ANSYS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9.600e+02
7.400e+02
5.200e+02
3.000e+02
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ANSYS
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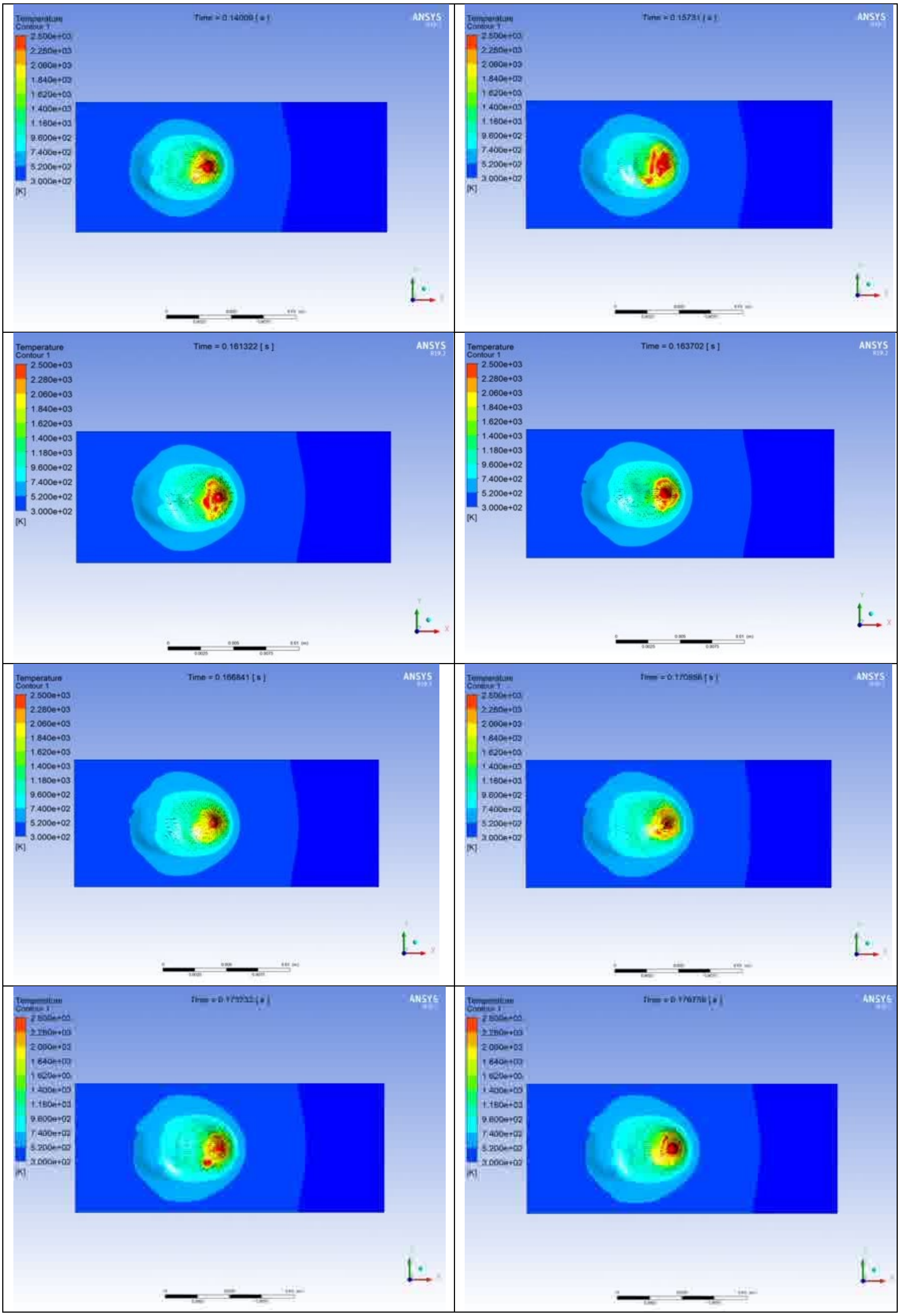
Temperature
Contour 1
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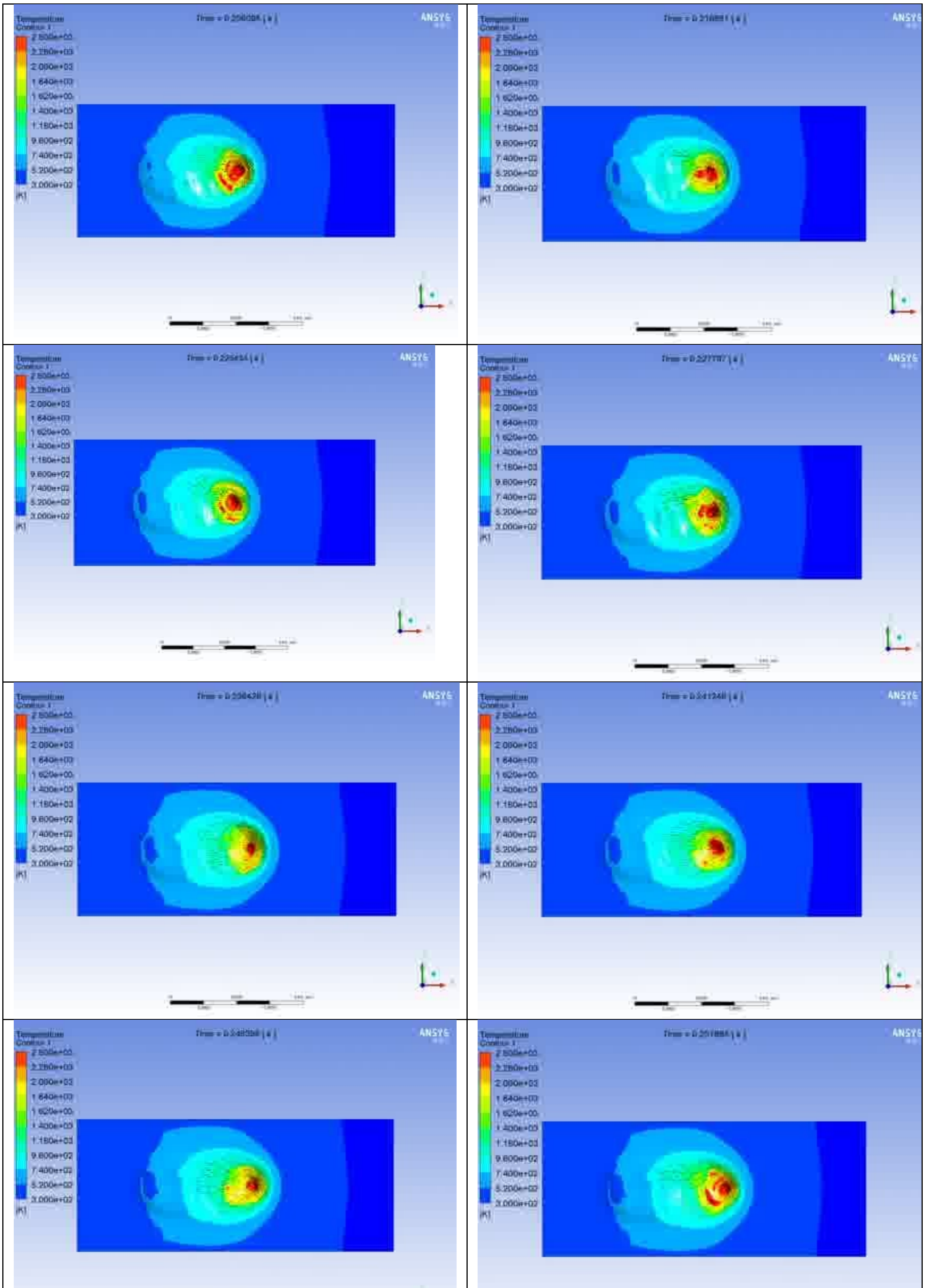
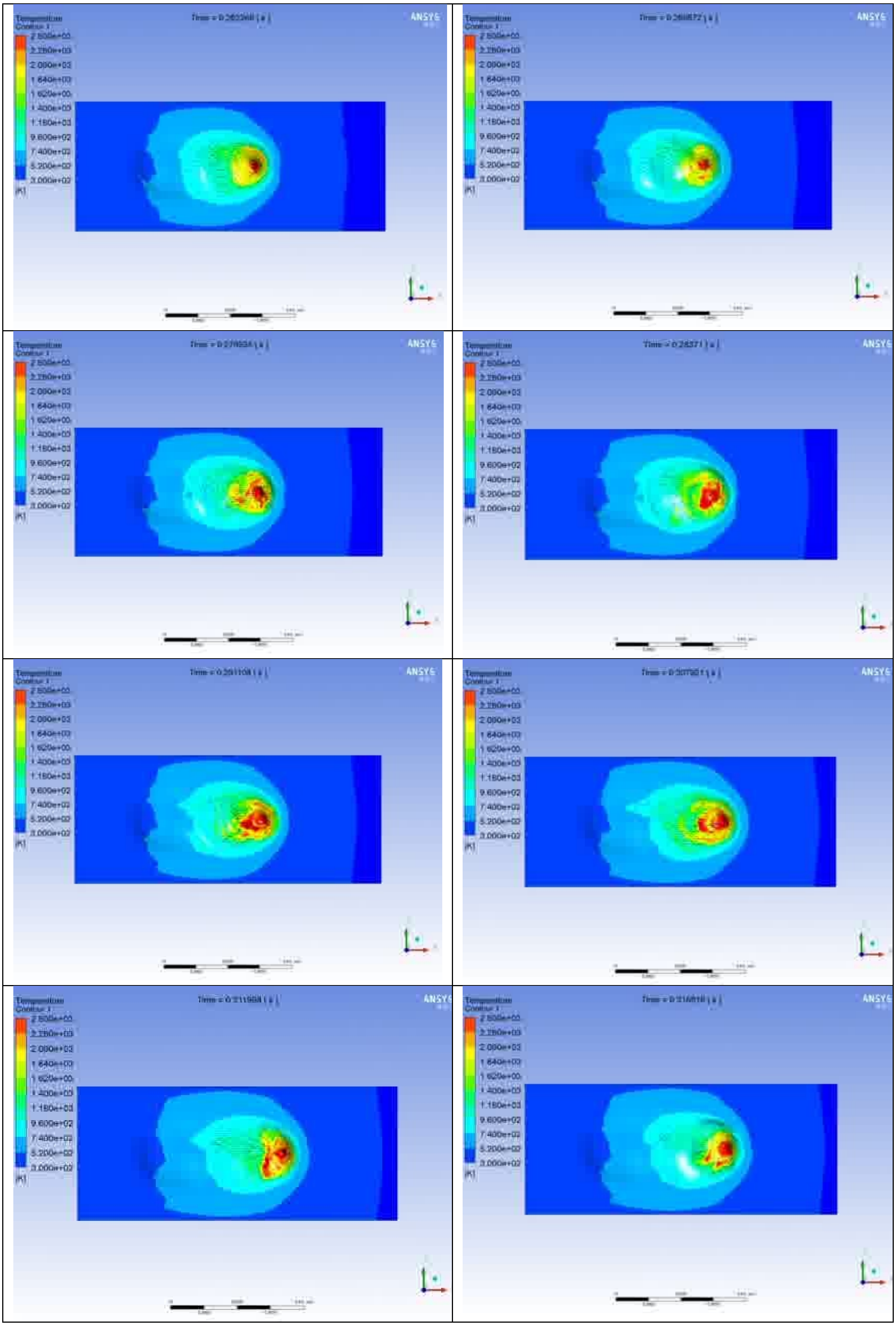
2.280e+03
2.060e+03
1.840e+03
1.620e+03
1.400e+03
1.180e+03
9.600e+02
7.400e+02
5.200e+02
3.000e+02
[K]
ANSYS
Time = 0.161322 [s]
Time = 0.163702 [s]
Time = 0.166841 [s]





11) FIXTURE DETAILS

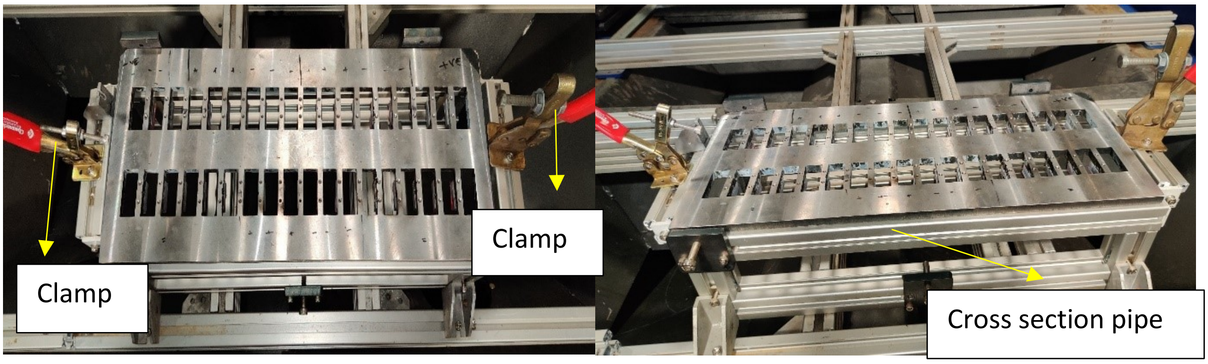


Figure 26 fixture used for laser welding

As shown in image a fixture was design by SLTL group for laser welding the material. The battery was place inside this box shape fixture and closed from the above. as shown in below **figure** silicon rubber was applied at the end so the battery won't get damaged or the person working on that cannot get shocked from the battery current.

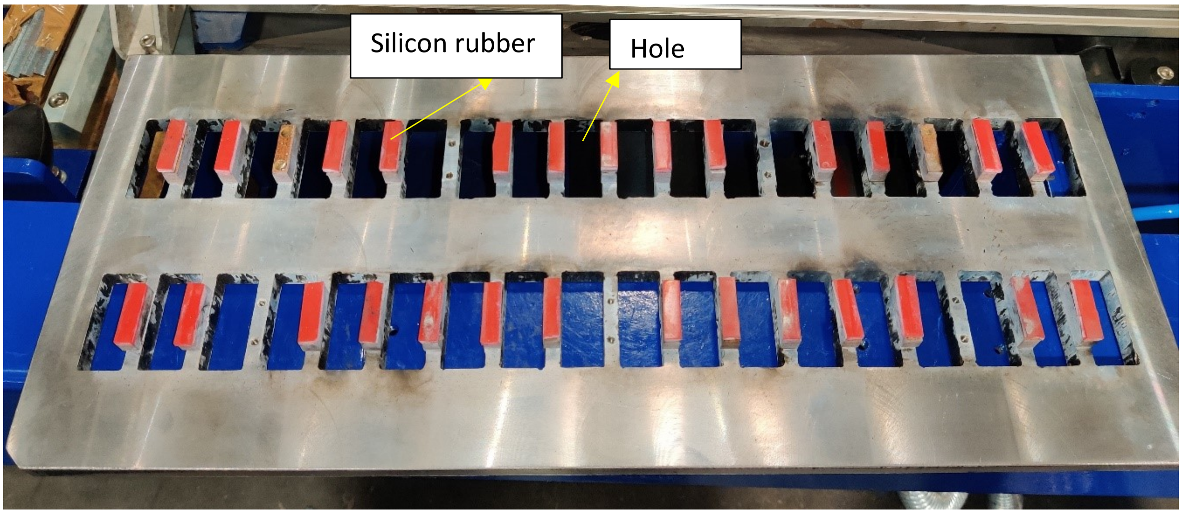


Figure 27 top part of fixture used to reduce the gap between laser welding

12) GANTT CHART

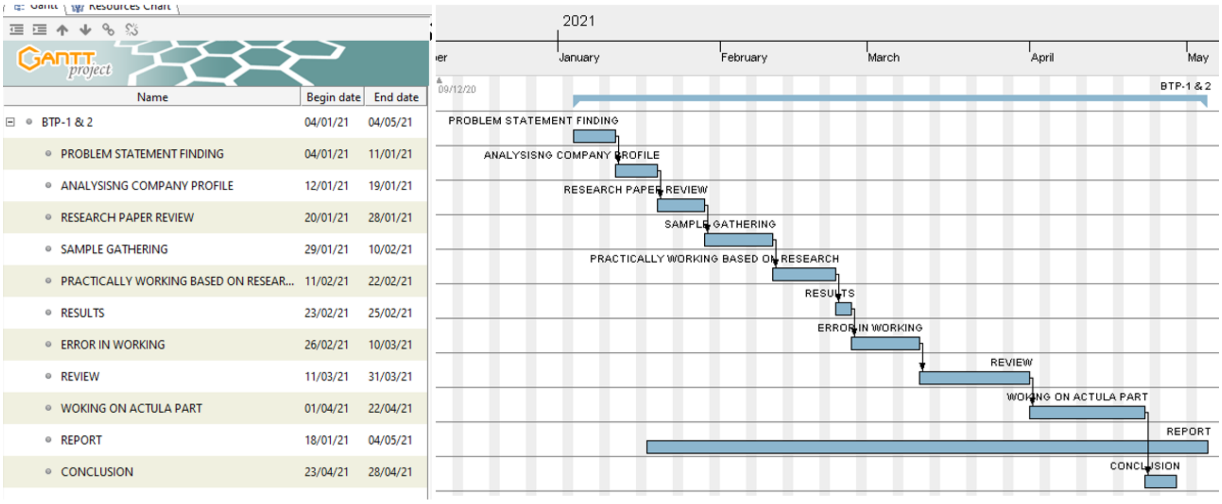


Figure 28 Gantt chart

In the first 5-8 days finding the problem statement as per company requirement then analysing company profile for few days. In next 15 days working on research paper and gathering data for implementation of laser welding of al-6063-t6 on lithium-ion battery. Based on gather sample an iteration was run practically to find out the actual parameter. After concluding the results and finding the perfect parameters working on actual part takes place based on that a report and conclusion is created and submitted to mentor as per guidelines.

Research and development on laser welding of aluminum 6063 to aluminum 6063 on lithium- ion battery"

13) CONCLUSION

- The review of results on laser welding of AL-6063 to AL-6063 on lithium-ion battery as a lap or spot weld are presented and discussed in this paper. There were some welding defects, such as bubble burst, hole, linear pattern of weld bend and calibrated of machine setup which is especially important for industrial applications are observed and then all these defects are reduced to a certain level of acceptance.
- The laser beam was de-focused at 255 mm from the real Z-axis value. The laser had a power of 1600 Watts and an 85 percent duty cycle. The welded bend had a thickness of less than 3 mm (nearly 2.6mm) and measured 36 mm length of weld. The speed was maintained at 1100 (mm/min). After selection of perfect parameters for laser weld we try that with lithium-ion battery and try to reduce defects in that too.
- We can get a deeper penetration in the material used to lap weld with higher welding strength, but surface voids and spatter are reduced. The estimated results are in good agreement with the measured data, indicating that the established model can adequately predict the responses within the limits of welding parameters used, according to the validation experiments.

14) FUTURE WORK

14.1) MACRO STRUCTURE EXAMINATION OF MATERIAL.

Macro testing is primarily used to assess the quality of welds. The cross-section of the welded object is polished and concentrated for testing. Porosity, lack of weld penetration, lack of side wall fusion, poor weld profile and other significant defects are considered according to the appropriate temperature level. This test is a requirement of international temperatures such as:

- BS EN ISO 5817, ASME IX, AWS D1.1

14.2) VIBRATION TEST AFTER WELDING.

Vibration test is a unique test for welded material. For upcoming day, it might be got trend to do vibration analysis of welded material as automobile requires. Now awaydays for electrical car it is necessary to test vibration for better life of car.

14.3) TECHNIQUES REDUCED REFLECTION WHILE WELDING.

Reflection in welding is something very difficult to deal with it. When a person needs to weld material with high reflection it is not possible to weld at low power machine.so green laser will be a future for laser welding.

14.4) UNIVERSAL TESTING MACHINE (UTM) OF WELDED PART IN MATERIAL.

Mechanical testing is a type of testing that utilizes dynamic force to revel the properties of the material. Various such type of testing like tensile test, hardness testing, impact test, phytic test, bend test and many more can be done to cheque the quality of material.

15) NOTATIONS AND ABBREVATIONS

Table 9 Notations and abbreviations

Nomenclature	
P(k)	Power involved in melting material.
A	Weld cross section area
v	Welding speed
p	Density
Cp	Heat capacity of solid
(ΔT)	Difference between the average weld melt temperature and the room temperature
L(f)	Latent heat of fusion
D	The depth of penetration of the heat (CM)
k	Thermal diffusivity of the material
t	Time

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