# *Laser Welding of Aluminium Alloy 2024: Experimental Investigation, Numerical Simulation and Optimization*

***A SUDHA KIRAN DUGGIRALA***

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***Doctor of Philosophy (Engineering)***

***School of Laser Science and Engineering***
***Faculty council of Interdisciplinary Studies, Law and Management***
***Jadavpur University***
***Kolkata, India***

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## SYNOPSIS

Laser beam welding of aluminium alloys has grown in popularity as a method for producing high-quality welds in recent years. To attain high-quality welds with reasonable process control, several researchers looked into the experimental and microstructure issues and resorted to numerical simulation. The physics behind complex welding phenomena and process optimisation can be understood using numerical approaches. The analytical models suggested in the literature can be improved by including temperature-dependent material properties, coupled physics, defining parameters beyond the vaporisation temperature, and Multiphysics to define the loading and boundary conditions.

AA 2024 is a crucial material for the industry, and a thorough analysis of its weldability is vital. But there are just a few investigations on the aluminium alloy 2024. The effect of process parameters on temperature distribution and the formation of weld profiles, Marangoni convection and its effect on weld metrics, and the formation of defects during laser welding of AA 2024 necessitate the development of an improved three-dimensional transient thermos-fluid model of laser beam welding. Thermo-fluid models have previously been described for several different materials, but the minimal attempt has been made to simulate the behaviour of AA 2024. The target material's thermophysical characteristics determine how well the welded components turn out. Once they are welded, these joints exhibit hot cracking, porosity, undercut, lack of penetration, and humping. A proper combination of process parameters is imperative to achieve the desired weld quality. The welding of aluminium alloy 2024, which is very helpful in the aerospace and defence industries, has not yet been thoroughly studied. A potential area of study would be the modelling and optimisation of laser beam welding of AA 2024. Keeping in mind previous research works and the current demand for study on laser welding of aluminium alloys, the following are the objectives of present research:

a. Development of a three-dimensional, transient, thermo-fluid model to simulate the laser welding process.

b. To study the temperature distribution during welding.
c. To estimate the weld pool dimensions.
d. To study the effect of Marangoni and non-dimensional numbers on weld geometry.
e. To analyse the influence of process parameters on the temperature profile and weld metrics.
f. To study the effect of non-dimensional numbers on the weld profile.
g. To extend the developed finite element model to study the formation of welding defects like humping.
h. To conduct experimental investigations of laser welding of aluminium alloy 2024
i. To conduct numerical models based on experimental results
j. To identify the effect of process parameters on weld width and depth of penetration
k. Study the microstructure of the heat-affected zone, fusion zone and base material.
l. To establish and implement process optimisation.

The mentioned objectives are accomplished by experimentation, numerical simulation and optimisation of the laser welding of aluminium alloy 2024 with a focus on obtaining successful welding. The summary of the work carried out for these objectives is recorded in the following chapters:

Chapter 1 gives a general and broad introduction to laser welding and different aspects of the process, and chapter 2 reviews the latest and relevant literature on the focussed topic. This chapter covers the literature published on analytical studies, experimentation and optimisation. The research gaps needed for the study and the problem hypothesis and description are mentioned in chapter 2. The material, equipment and various methodologies employed in reaching the objectives are mentioned in chapter 3. Chapter 4 discusses the 3-dimensional transient thermos-fluid model developed in this study process. Design of experiments, the results of experiments and the prediction of the weld metrics are discussed in chapter 5, and the metallographic and microscopic images are described in chapter 6. This chapter also gives the 3-dimensional thermos-fluid models to predict the humping phenomenon that occurs in welding. The weld parameters are optimised in chapter 7, with chapter 8 mentioning the general conclusions and future scope. The thesis ends with a bibliography relevant to this study.

The brief methodology of the work is as follows:

The commercial finite element programme COMSOL multi-physics is used to acquire the time-temperature history and weld defects. The numerical model's output is validated against the experiments, and they fairly concur. A parametric sensitivity study is conducted to ascertain how various input parameter values affect a particular response based on the model's output.

The three-dimensional thermo-fluid model on humping is developed to explore the influence of factors on hump development and is used only to research the production of faults. The findings indicate that when laser welding is done without considering the scanning speed and frequency, the peak power is the most influential factor, whereas the pulse width increases the hump marginally. The experiments are designed using the response surface methodology. The four factor-four level design yielded 30 experiments which were carried out on Nd: YAG laser welding machine. The aluminium alloy 2024 samples of size 75mm x 25mm x 2mm are cut, filed, polished, and prepared for welding. Once the welding is performed using an appropriate fixture, the samples are polished and etched according to the standard procedures in the American welding society C7.2 document and ISO recommendations. The samples are then examined using the optical microscope to evaluate the preliminary features on the surface, the metallurgical microscope for the examination of the heat-affected zone and properties of weld bead that occurred during the welding process and a scanning electron microscope to understand the phases that occurred in the process. The weld metrics, penetration depth and weld width, are predicted using the Gaussian process regression, and the developed regression model is validated with the experiments. The numerous process parameters influencing welding are optimised using the crowding distance variant of the particle swarm optimisation technique.

It is anticipated that the present research findings will not only shed new light on fundamental and applied research in the field of laser welding of aluminium alloys but proves to be quite valuable for the manufacturing sector and tool rooms to make a quantum leap into the realm of today's needs for the welding of different light metal alloys in light of the shifting physical requirements of the parts or products.

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Professor
Production Engineering Department
Jadavpur University
Kolkata 700 032

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DR. BAPPA ACHERJEE
ASSISTANT PROFESSOR
DEPARTMENT OF PRODUCTION & INDUSTRIAL ENGINEERING
BIRLA INSTITUTE OF TECHNOLOGY
MESRA, RANCHI - 835215, INDIA