International Journal of Engineering & Extended Technologies Research (IJEETR)

|ISSN: 2322-0163| www.ijeetr.com | A Bimonthly, Peer Reviewed, Scholarly Indexed Journal |

| Volume 8, Issue 2, March - April 2026 |

DOI:10.15662/IJEETR.2026.0802290

# Experimental Investigations and Parametric Optimisation of Joining Copper and Stainless Steel by Electron Beam Welding for Aerospace Applications

**Dr.M.Panneerselvam[1], Adhisha A[2], Arunpandi K[3], Bharath K[4]**

Professor, Department of Aeronautical Engineering, MAM School of Engineering, Siruganur, Trichy, Tamil Nadu, India[1]

U.G. Students, Department of Aeronautical Engineering, MAM School of Engineering, Siruganur, Trichy, Tamil Nadu, India[2-4]

**Publication History:** Received: 25.02.2026; Revised: 20.03.2026; Accepted: 25.03. 2026; Published: 28.03.2026.

**ABSTRACT:** The demand for lightweight, high-performance, and thermally efficient materials in aerospace applications has led to increased interest in dissimilar metal joining, particularly copper and stainless steel. However, the significant differences in their thermal and physical properties present major challenges during welding. This study investigates the feasibility of joining copper and stainless steel using Electron Beam Welding (EBW) and focuses on the experimental evaluation and parametric optimisation of the process. Key welding parameters such as beam current, welding speed, beam offset, and beam power are analyzed to understand their influence on weld quality, microstructure, and mechanical properties. Experimental results demonstrate that EBW produces high-quality joints with minimal heat-affected zones and reduced distortion. Optimal parameter settings significantly improve tensile strength, hardness, and microstructural uniformity. The study confirms that EBW is a suitable and reliable technique for aerospace-grade dissimilar metal joining.

**KEYWORDS:** Electron Beam Welding, Copper–Stainless Steel Joining, Aerospace Applications, Dissimilar Metal Welding, Heat Input Optimization, Weld Microstructure, Mechanical Properties

## I. INTRODUCTION

Modern aerospace systems require materials that combine high strength, corrosion resistance, and excellent thermal conductivity. Copper and stainless steel are widely used due to their complementary properties: copper provides superior thermal and electrical conductivity, while stainless steel offers mechanical strength and corrosion resistance. However, joining these materials is difficult due to differences in melting points, thermal conductivity, and metallurgical incompatibility.

Conventional welding processes often result in defects such as cracks, porosity, and brittle intermetallic compounds. Electron Beam Welding (EBW) offers a promising solution due to its high energy density, deep penetration capability, and vacuum environment, which minimizes contamination and oxidation . This study aims to experimentally investigate EBW of copper and stainless steel and optimise process parameters for improved weld performance.

## II. LITERATURE REVIEW

Recent studies have demonstrated the effectiveness of EBW in joining dissimilar metals. Research shows that welding parameters such as beam current, welding speed, and beam offset significantly influence weld quality and mechanical properties . Beam current has been identified as the most critical parameter affecting penetration depth and weld strength.

Studies on copper–stainless steel joints reveal that proper control of beam power and offset can minimize defects and improve joint strength. Lower beam power levels tend to produce finer microstructures and higher tensile strength, while higher power increases ductility but reduces strength . Additionally, beam oscillation techniques have been shown to reduce porosity and improve material mixing.

|ISSN: 2322-0163| www.ijeetr.com | A Bimonthly, Peer Reviewed, Scholarly Indexed Journal |

| Volume 8, Issue 2, March - April 2026 |

DOI:10.15662/IJEETR.2026.0802290

Despite these advancements, challenges remain in controlling intermetallic phase formation and achieving optimal parameter combinations for aerospace applications. This study addresses these gaps through systematic experimentation and optimisation.

## III. MATERIALS AND METHODS

### 3.1 Materials

The materials used in this study include commercially pure copper and AISI 304 stainless steel. These materials are commonly used in aerospace heat exchangers, fuel systems, and structural components.

### 3.2 Experimental Setup

Electron Beam Welding was carried out in a high-vacuum chamber to ensure contamination-free welds. The specimens were prepared with proper surface cleaning and alignment before welding.

### 3.3 Process Parameters

The following parameters were varied during experimentation:

- Beam current (40–70 mA)
- Welding speed (0.5–1 cm/s)
- Beam power (2400–3600 W)
- Beam offset (0.3–0.5 mm toward copper side)

These parameters were selected based on prior research indicating their strong influence on weld quality.

### 3.4 Characterisation Techniques

The welded joints were evaluated using:

- Optical microscopy and SEM for microstructural analysis
- Tensile testing for mechanical strength
- Microhardness testing across weld zones
- XRD analysis for phase identification

## IV. RESULTS AND DISCUSSION

### 4.1 Weld Morphology

The EBW process produced defect-free welds with narrow heat-affected zones. The high energy density and localized heating minimized distortion and residual stresses.

### 4.2 Microstructural Analysis

The weld zone exhibited a *मिश्रित* microstructure consisting of copper-rich and iron-rich phases. The formation of solid solutions between copper and iron was observed, along with some undissolved copper regions. The microstructure varied significantly with beam power and welding speed.

At lower beam power, finer grains were observed, resulting in higher strength. Increasing beam power led to coarser grains and increased ductility but reduced strength .

### 4.3 Mechanical Properties

The tensile strength of the welded joints was highest at moderate beam power (2400–3000 W). Excessive beam power resulted in reduced strength due to increased grain size and phase segregation.

Microhardness measurements showed variation across the weld zone, with higher hardness near the stainless steel region and lower hardness near the copper region. This variation is attributed to differences in material composition and cooling rates.

### 4.4 Effect of Process Parameters

**Beam Current**

Beam current significantly affects penetration depth and weld strength. Higher beam current increases penetration but may cause excessive melting and defects if not controlled properly .

**Welding Speed**

|ISSN: 2322-0163| www.ijeetr.com | A Bimonthly, Peer Reviewed, Scholarly Indexed Journal |

| Volume 8, Issue 2, March - April 2026 |

DOI:10.15662/IJEETR.2026.0802290

Higher welding speed reduces heat input, resulting in narrower weld zones and finer microstructures. However, excessively high speeds may lead to incomplete fusion.

**Beam Offset**

A slight beam offset toward the copper side improves weld quality by balancing heat distribution and reducing defects.

**Beam Power**

Beam power plays a critical role in determining microstructure and mechanical properties. Optimal power levels produce strong, defect-free joints, while excessive power leads to reduced strength and increased ductility.

## V. PARAMETRIC OPTIMISATION

Parametric optimisation was carried out using experimental observations and statistical analysis. The optimal parameter combination was found to be:

- Beam current: ~50–60 mA
- Welding speed: ~0.5 cm/s
- Beam power: ~2400–3000 W
- Beam offset: ~0.3 mm toward copper

These parameters resulted in:

- Maximum tensile strength
- Uniform microstructure
- Minimal defects and porosity

Optimisation results indicate that careful control of heat input and beam positioning is essential for achieving high-quality welds.

## VI. APPLICATIONS IN AEROSPACE

The successful joining of copper and stainless steel using EBW has significant implications for aerospace applications, including:

- Heat exchangers and cooling systems
- Fuel and hydraulic systems
- Electronic packaging and thermal management
- Structural components requiring dissimilar material properties

EBW provides high reliability, precision, and repeatability, making it suitable for critical aerospace components.

## VII. ADVANTAGES AND LIMITATIONS

**Advantages**

- High precision and deep penetration
- Minimal heat-affected zone
- Reduced distortion and residual stress
- Ability to join dissimilar metals
- High repeatability and automation

**Limitations**

- High equipment cost
- Requirement of vacuum environment
- Sensitivity to parameter variations
- Limited accessibility for large components

## VIII. CONCLUSION

This study demonstrates that Electron Beam Welding is an effective technique for joining copper and stainless steel for aerospace applications. Experimental investigations reveal that welding parameters significantly influence weld quality, microstructure, and mechanical properties. Optimal parameter selection results in strong, defect-free joints with desirable mechanical characteristics.

|ISSN: 2322-0163| www.ijeetr.com | A Bimonthly, Peer Reviewed, Scholarly Indexed Journal |

| Volume 8, Issue 2, March - April 2026 |

DOI:10.15662/IJEETR.2026.0802290

The findings highlight the importance of parametric optimisation in achieving reliable dissimilar metal joints. EBW offers a promising solution for advanced aerospace manufacturing, where performance and reliability are critical.

**REFERENCES**

1. Duraisamy, S., et al. (2025). Electron beam welding parameters for copper and dissimilar metals: Optimization and analysis. *Results in Engineering*.
2. Kaisheva, D., et al. (2022). Influence of beam power on structure and mechanical properties of electron-beam welded copper–stainless steel joints. *Metals*, 12(5), 737.
3. de Zuniga, M.O., et al. (2026). Machine learning-supported prognosis of electron beam welding quality. *Journal of Manufacturing Processes*.
4. C.Nagarajan and M.Madheswaran - 'Stability Analysis of Series Parallel Resonant Converter with Fuzzy Logic Controller Using State Space Techniques'- Taylor &Francis, Electric Power Components and Systems, Vol.39 (8), pp.780-793, May 2011. DOI: 10.1080/15325008.2010.541746
5. C.Nagarajan and M.Madheswaran - 'Experimental verification and stability state space analysis of CLL-T Series Parallel Resonant Converter' - Journal of Electrical Engineering, Vol.63 (6), pp.365-372, Dec.2012. DOI: 10.2478/v10187-012-0054-2
6. C.Nagarajan and M.Madheswaran - 'Performance Analysis of LCL-T Resonant Converter with Fuzzy/PID Using State Space Analysis'- Springer, Electrical Engineering, Vol.93 (3), pp.167-178, September 2011. DOI 10.1007/s00202-011-0203-9
7. S.Tamilselvi, R.Prakash, C.Nagarajan,"Solar System Integrated Smart Grid Utilizing Hybrid Coot-Genetic Algorithm Optimized ANN Controller" Iranian Journal Of Science And Technology-Transactions Of Electrical Engineering, DOI10.1007/s40998-025-00917-z,2025
8. S.Tamilselvi, R.Prakash, C.Nagarajan," Adaptive sliding mode control of multilevel grid-connected inverters using reinforcement learning for enhanced LVRT performance" Electric Power Systems Research 253 (2026) 112428, doi.org/10.1016/j.epsr.2025.112428
9. S.Thirunavukkarasu, C. Nagarajan, 2024, "Performance Investigation on OCF and SCF study in BLDC machine using FTANN Controller," Journal of Electrical Engineering And Technology, Volume 20, pages 2675–2688, (2025), doi.org/10.1007/s42835-024-02126-w
10. C. Nagarajan, M.Madheswaran and D.Ramasubramanian- 'Development of DSP based Robust Control Method for General Resonant Converter Topologies using Transfer Function Model'- *Acta Electrotechnica et Informatica Journal* , Vol.13 (2), pp.18-31,April-June.2013, DOI: 10.2478/aeei-2013-0025.
11. C.Nagarajan and M.Madheswaran - 'DSP Based Fuzzy Controller for Series Parallel Resonant converter'- *Springer, Frontiers of Electrical and Electronic Engineering*, Vol. 7(4), pp. 438-446, Dec.12. DOI 10.1007/s11460-012-0212-0.
12. C.Nagarajan and M.Madheswaran - 'Experimental Study and steady state stability analysis of CLL-T Series Parallel Resonant Converter with Fuzzy controller using State Space Analysis'- *Iranian Journal of Electrical & Electronic Engineering*, Vol.8 (3), pp.259-267, September 2012.
13. C.Nagarajan and M.Madheswaran, "Analysis and Simulation of LCL Series Resonant Full Bridge Converter Using PWM Technique with Load Independent Operation" has been presented in ICTES'08, a IEEE / IET International Conference organized by M.G.R.University, Chennai.Vol.no.1, pp.190-195, Dec.2007
14. Suganthi Mullainathan, Ramesh Natarajan, "An SPSS and CNN modelling based quality assessment using ceramic materials and membrane filtration techniques", Revista Materia (Rio J.) Vol. 30, 2025, DOI: https://doi.org/10.1590/1517-7076-RMAT-2024-0721
15. M Suganthi, N Ramesh, "Treatment of water using natural zeolite as membrane filter", Journal of Environmental Protection and Ecology, Volume 23, Issue 2, pp: 520-530,2022
16. Pavlík, M., et al. (2025). Chemical composition and shear strength of electron beam welded Cu–AISI 304 joints. *Journal of Materials Engineering and Performance*.
17. Rajendran, A.R., et al. (2024). Quantitative phase analysis of EBW copper–stainless steel joints using XRD and SEM-EDX. *Asia-Pacific Journal of Science and Technology*.
18. Guo, Y., et al. (2023). Effect of beam offset on microstructure and mechanical properties of EBW dissimilar joints. *Journal of Materials Processing Technology*.
19. Kar, J., et al. (2022). Porosity analysis in electron beam welded copper–stainless steel joints. *Vacuum*.
20. Zhou, Y., et al. (2023). Microstructure evolution and mechanical behavior of EBW dissimilar metal joints. *Materials Science and Engineering A*.
21. Li, X., et al. (2024). Optimization of electron beam welding parameters using statistical methods. *Optics & Laser Technology*.

|ISSN: 2322-0163| www.ijeetr.com | A Bimonthly, Peer Reviewed, Scholarly Indexed Journal |

| Volume 8, Issue 2, March - April 2026 |

DOI:10.15662/IJEETR.2026.0802290


22. Wang, H., et al. (2022). Advanced welding techniques for dissimilar metals in aerospace applications. *Journal of Manufacturing Processes*.
23. **Kiran, A., Rubini, P., & Kumar, S. S. (2025).** Comprehensive review of privacy, utility and fairness offered by synthetic data. *IEEE Access.*
24. **Gopinathan, V. R. (2024).** Real-Time Financial Risk Intelligence Using Secure-by-Design AI in SAP-Enabled Cloud Digital Banking. *International Journal of Computer Technology and Electronics Communication, 7(6), 9837-9845.*
25. **Udayakumar, R., Elankavi, R., Vimal, R., & Sugumar, R. (2023).** Improved Particle Swarm Optimization with Deep Learning-Based Municipal Solid Waste Management in Smart Cities. *Environmental & Social Management Journal, 17(4).*
26. **Anand, L. (2023).** An Intelligent AI and ML–Driven Cloud Security Framework for Financial Workflows and Wastewater Analytics. *International Journal of Humanities and Information Technology, 5(02), 87-94.*
27. **Soundappan, S. J. (2020).** Big Data Analytics in Healthcare: Applications for Pandemic Forecasting. *International Journal of Advanced Research in Computer Science & Technology, 3(1), 2248-2253.*
28. **Rajasekar, M. (2024).** Real-Time Predictive DevOps Intelligence for Risk-Aware Digital Business Processes in Cloud and SAP Ecosystems. *International Journal of Advanced Research in Computer Science & Technology, 7(4), 10713-10718.*
29. **Poornima, G., & Anand, L. (2024, May). Novel AI Multimodal Approach for Combating Against Pulmonary Carcinoma. In 2024 5th International Conference for Emerging Technology (INCET) (pp. 1-6). IEEE.**
30. **Prabha, P. S., & Rengarajan, A. (2025).** Adaptive Cloud Resource Allocation Using Attention-Driven Deep Reinforcement Learning. *Engineering, Technology & Applied Science Research, 15(6), 29334-29340.*
31. **Jagadeesh, S., & Sugumar, R. (2017).** A Comparative study on Artificial Bee Colony with modified ABC algorithm. *European Journal of Applied Sciences, 9(5), 243-248.*
32. **Varma, K. K., & Anand, L. (2025, March). Deep Learning Driven Proactive Auto Scaler for High-Quality Cloud Services. In International Conference on Computing and Communication Systems for Industrial Applications (pp. 329-338). Singapore: Springer Nature Singapore.**
33. **Kumar, S. A., & Anand, L. (2025). A Novel EEG-Based Deep Learning Framework for Enhancing Communication in Locked-In Syndrome Using P300 Speller and Attention Mechanisms. KSII TRANSACTIONS ON INTERNET AND INFORMATION SYSTEMS, 19(11), 3841-3855.**
34. **Poornima, G., & Anand, L. (2025). Medical image fusion model using CT and MRI images based on dual scale weighted fusion based residual attention network with encoder-decoder architecture. Biomedical Signal Processing and Control, 108, 107932.**
35. **Archana, R., & Anand, L. (2025). Residual u-net with Self-Attention based deep convolutional adaptive capsule network for liver cancer segmentation and classification. Biomedical Signal Processing and Control, 105, 107665.Kumar, S. A., & Anand, L. (2025).** A Novel EEG-Based Deep Learning Framework for Enhancing Communication in Locked-In Syndrome Using P300 Speller and Attention Mechanisms. *KSII Transactions on Internet and Information Systems, 19(11), 3841-3855.*
36. **Rengarajan, A. (2025).** Cloud-Based AI-Driven Threat Detection Framework for Smart Grid Cybersecurity. *International Journal of Future Innovative Science and Technology, 8(6), 16065.*
37. **Murugeshwari, B., Sudharson, K., Panimalar, S. P., Shanmugapriya, M., & Abinaya, M. (2020).** SAFE–Secure Authentication in Federated Environment using CEG Key code.
38. **Raj A. A., & Sugumar, R. (2023).** Early Detection of COVID-19 with Impact on Cardiovascular Complications using CNN Utilising Pre-Processed Chest X-Ray Images. *2023 International Conference on Applied Intelligence and Sustainable Computing (ICAISC), IEEE.*
39. **Jagadeesh, S., & Sugumar, R. (2017). A Comparative study on Artificial Bee Colony with modified ABC algorithm. European Journal of Applied Sciences, 9(5), 243-248.**
40. **Selvi, G. V., Anbarasan, A. B., Murthy, B. A., & Prabavathy, S. (2023).** An Application Oriented Integrated Unequal Clustering Algorithm for Wireless Sensor Network. In *Underwater Vehicle Control and Communication Systems Based on Machine Learning Techniques* (pp. 140-154). CRC Press.
41. **Sruthi, R. S., Ananya, S., & Murugeshwari, B. (2010).** Web Based Virtual Control System Laboratory and On-Line Temperature Control of Electrophoresis Equipment using LabVIEW. *International Journal of Computer Applications, 975, 8887.*
42. **Vimal Raja, G. (2021).** Mining Customer Sentiments from Financial Feedback and Reviews using Data Mining Algorithms. *International Journal of Innovative Research in Computer and Communication Engineering, 9(12), 14705-14710.*
43. MATHEW, A. R. (2025). Neurosecurity and Brain-Computer Interfaces.

|ISSN: 2322-0163| www.ijeetr.com | A Bimonthly, Peer Reviewed, Scholarly Indexed Journal |

| Volume 8, Issue 2, March - April 2026 |

DOI:10.15662/IJEETR.2026.0802290

44. Soundappan, S. J. (2024). AI-Driven Customer Intelligence in Enterprise Lakehouse Systems Sentiment Mining Governance-Aware Analytics and Real-Time Data Synchronization. International Journal of Advanced Engineering Science and Information Technology (IJAESIT), 7(5), 14905.
45. Mathew, A. (2025). Human–AI Collaboration in Security Operations: Measuring Alert Trust, Automation Bias, and Analyst Upskilling in AI-Augmented SOC Environments. International Journal of Computer Technology and Electronics Communication, 8(5), 11375-11380.
46. Soundappan, S. J. (2022). AI-Based Fault Detection and Isolation for Reliability in Modern Power Systems. International Journal of Research Publications in Engineering, Technology and Management (IJRPETM), 5(4), 7106-7110.
47. **Poornima, G., & Anand, L. (2024, April). Effective Machine Learning Methods for the Detection of Pulmonary Carcinoma. In 2024 Ninth International Conference on Science Technology Engineering and Mathematics (ICONSTEM) (pp. 1-7). IEEE.Garg, V. K., Soundappan, S. J., & Kaur, E. M. (2020).** Enhancement in intrusion detection system for WLAN using genetic algorithms. *South Asian Research Journal of Engineering and Technology, 2(6), 62–64.*
48. Rengarajan, A., Jayakumar, C., & Sugumar, R. (2012). Optimization Of Recent Attacks Using Internet Protocol. National Journal of System and Information Technology, 5(1), 8.
49. Mathew, A. (2024). AI TRiSM: Trust, Risk, and Security Management in Cybersecurity. Cybersecurity, 4(3), 84-90.
50. Mathew, A. (2025). Deep seek vs. ChatGPT: A deep dive into AI Language mastery. Int J Multidisciplinary Res, 7(1), 1-5.