Synopsis of PhD Thesis

NUMERICAL AND EXPERIMENTAL STUDIES FOR OPTIMIZATION OF LASER WELDING OF 2205 DUPLEX STAINLESS STEEL

Synopsis submitted by

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The present work proposes to explore laser welding of duplex 2205 stainless steel through numerical and experimental methods for optimization of process parameters. Different types of welded joints are used in industry. Laser welding can be accomplished with comparatively lesser amount of heat and the heat can be delivered through a smaller and precise beam resulting in less residual deformation and a deeper penetration which helps in achieving a higher weld strength, a smaller bead width with better aesthetics, as well as a narrow heat affected zone (HAZ) such that lesser amount is affected by the thermal degradation process. Due to such advantages laser welding offers a promising route for welding compared to other welding techniques. Why we choose laser welding process was described above but reason behind choosing 2205 duplex stainless is its unique properties which should be explored much. Duplex stainless steels (DSS) represent a class of stainless steels with dual microstructure consisting of approximately equal proportions of ferrite and austenite phases. This balanced microstructure offers a favorable combination of mechanical strength and corrosion resistance, rendering DSS a popular choice for pipelines, handling high pressure and corrosive fluids. Along this, mechanical and chemical properties are being stable in elevated temperature. As it is predictable to reach very high temperature in welding process, the consistency of properties on such high heat is desirable. Application of the Duplex stainless-steel finds use in diverse fields, such as automotive industries, process industries, aerospace, marine and fabrication industries.

Laser welding process includes some process parameters to achieve some response parameters. It is known that a welding will be defined as satisfactory or complete only if it can offer quite high strength in joints. To ensure higher strength in joints we have to aim maximum penetration of heat into the material as well as minimum bead width so that heat affected zone can be minimal. A large area of heat affected zone can rise brittleness of weld materials. Higher strength weld joints require precise selection range of input or process parameters. Laser power, welding speed, beam diameter and pulse width are generally applied as laser welding process parameters where depth of penetration, bead width, ultimate tensile strength, yield strength, elongation and young’s modulus are required response parameters to identify the quality of welding. So, for accruing high quality strength joints we have to identify optimum process parameters. In experimental way if we try to recognize this optimum range then we have to complete a very large number of experiments which will be very expensive and time consuming as well. Due to this reason in present research we decided to develop a three-dimensional finite element model utilizing COMSOL MULTIPHYSICS® for laser welding simulation from which we can get idea of proper range of process parameters.

At first, we developed an isotropic model for laser welding including phase change with physical and temperature depended thermal properties of material. We applied power, welding speed and beam diameter as input. Symmetry was taken into account throughout the surface of the welding orientation. In order to choose the right quantity of components, a series of convergence trials were carried out, paying special attention to the depth axis along with regions adjacent to the weld alignment. Extremely condensed mesh was produced around the area close to the weld line, and coarse mesh was proposed around the left-over area. As output we are restricted to achieve only depth of penetration, bead width and temperature distribution from the simulation model. Mechanical characterization is not possible from the model. We have then validated those outputs with published results to check its adequacy and noticed that this method provides acceptable match though not exactly identical. Now based on this process we simulated quite a large number of welding to get a safe operating window and optimum process parameters, based on which we can go ahead for experimental investigation. But in actual, thermal properties are not consistent with elevated temperature in each direction, so isotropic simulation process needs to upgrade into anisotropic process. We have followed the anisotropic approach for simulation model and done some welding experiments to validate the results.

As we stated above that only depth of penetration and bead width can be measured from model, so we compared these two responses and found better match against isotropic model. With the help of optical microscope, we measured depth and width of fusion zone, additionally we identified the heat affected zone. For better realization of weld, base and HAZ zone we utilized scanning electron microscope, from where we understood the grain orientation and grain size variations at different zone. Welding quality cannot be only defined by depth of penetration and bead width without mechanical characterization. So, we decided to go for mechanical characterization of those few welded sample along with base metal by doing tensile test and hardness test. Here we noticed that hardness is very high at weld zone where after welding base zone hardness remain unchanged regarding base metal and HAZ has very low hardness value. But for tensile test we found that base material offers higher ultimate tensile strength and elongation than welded materials. So, a clear mechanical property degradation was noticed.

Only depth of penetration and bead width are not sufficient at all to provide good quality weld until it offers satisfactory strength. So still there are some requirements to upgrade the present simulation model. So far for both simulation process we only consider isotropic and anisotropic approach but it is obvious to consider fluid flow as in reality there is a situation molten metals flows, so to achieve accurate simulation it is required to include the CFD in finite element method. Three numerical models are developed considering the flow in the molten pool to be laminar in the first model and turbulent in the two other models. We measured depth and width from these three CFD model and validate with experimented one. We found a turbulent model provide best match to the experimented result so far against isotropic and anisotropic model. Although we were still unable to found the strength of joints from this CFD model so we decided to do a bunch of experimental welding investigation to check depth of penetration, bead width along with ultimate tensile strength and elongation taken into account. And depending on the experimental result we create a design matrix to analyse response parameters by developing mathematical corelation between process and response parameters to predict future responses with another set of process parameters. Also, we upgrade the optimization model with taking into account depth of penetration, bead width along with ultimate tensile strength and elongation and found optimum process parameters which can deliver maximum ultimate strength and elongation with maximum penetration and minimum bead width. Considering weld response parameters like depth of penetration, bead width along with mechanical properties like ultimate tensile strength and elongation is appraisable to identify the optimum weld conditions under laser welding process. The final part concludes the results of the various studies and also presents the future scope the work.

SAcharyya 19.09.23

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List of Publications (accepted/communicated) of Mrs. Aritra Ghosh

1. “Numerical Simulation of the Laser Welding of 2205 Duplex Stainless Steel”, A. Ghosh, D. Misra and S.K. Acharyya, International Journal of Laser Science 2019, Vol. 1, pp. 293–313.
3. “Experimental and Numerical Investigation on Laser Welding of 2205 Duplex Stainless Steel”, Aritra Ghosh, Dipten Misra, Sanjib Kumar Acharyya, Lasers in Manufacturing and Materials Processing (2019) 6:228–246.
4. “Comparison of Molten Pool Behaviour of Different Numerical Models for Laser Welding of 2205 Duplex Stainless Steel”, Aritra Ghosh, Paramasivan Kalvettukaran, Dipten Misra, Sanjib Kumar Acharyya, Lasers in Manufacturing and Materials Processing (2019) 6:228–246.
5. “Estimation of Weld-Bead Dimensions in Laser Butt Welding of 2205 Duplex Stainless Steel”, Aritra Ghosh and Dipten Misra, National Conference on Advanced Functional Materials Processing & Manufacturing (NCAFMPM-2017) CSIR-CMERI Durgapur.
6. “Experimental Investigation on Laser Welding of 2205 Duplex stainless steel”, Aritra Ghosh and Dipten Misra, INCOM18: Proceedings of the 1st International Conference on Mechanical Engineering Jadavpur University Kolkata.
7. “Experimental Investigation on the Effect of Pulse Width on Laser Welding of 2205 Duplex Stainless Steel”, Aritra Ghosh, Paramasivan Kalvettukaran, Dipten Misra, Sanjib Kumar Acharyya, Virtual International Conference on Recent Advancements in Mechanical Engineering (ICRAME 2021)

To be communicated

1. “Experimental study on weld pool dimensions and mechanical properties of laser-welded 2205 duplex stainless steel”, Aritra Ghosh, Paramasivan Kalvettukaran, Dipten Misra, Sanjib Kumar Acharyya.