ABSTRACT

Laser bending process is an emerging technique in sheet metal forming in which laser heating is utilized to shape a metal sheet. The advantages of this technique over the other traditional metal forming technologies includes simple process, high flexibility, non-contact processing, and negligible spring back. The method is useful for producing very small and precise bend angles. Laser bending relies on the localized heating and thermal expansion induced by the laser beam to achieve the desired bending. This flexibility allows for the production of complex shapes. It is also possible to generate complex shapes by employing a suitable scanning strategy. Laser bending can be used for ferrous, nonferrous materials and even brittle and plastic materials in some cases. Literature contains the impact of process variables like laser power, scanning speed, beam diameter, number of scans, and beam shape on laser bending. Additionally, the material characteristics, such as material properties, sheet dimensions, and coating, had a substantial impact on the bending performance. As research and development efforts continue to advance laser bending technology, its industrial adoption is likely to grow further, reflecting its significant potential in modern manufacturing processes. Several research groups are actively investigating methods to improve the characteristics of laser bending. Several analytical and numerical models have been developed to improve laser bending efficiency. Many studies involved external load in laser bending to increase the bend angle. Several studies have focused on the waiting time required between consecutive scans during the laser bending process. However, scant attention has been given to the optimization of laser process parameters with forced cooling condition and laser bending with the application of electromagnet force. Limited research outputs are available in the literature about the bottom forced cooling and electromagnetic force assisted laser bending process. The focus of this thesis is on enhancement of accuracy and efficiency of the laser based bending process.

In this work, the deformation of a mild steel sheet subjected to laser irradiation is explored through a series of experiments. The parameters are selected on the basis of a comprehensive literature review. The effect of input variables like laser power, scan speed and beam diameter are studied. The experiments are performed to study the influence of various cooling environments (natural and forced cooling environments) on laser bending of mild steel (MS) sheets. Forced cooling assisted laser bending

experiments on mild steel revealed that the vital combination of process variables and forced cooling condition provides a high bending angle and enhances the mechanical characteristics of the bent specimen. The forced cooling condition was more effective with lower scanning speed, smaller beam diameter, and higher laser power. Temperature distribution shows the cumulative effect of multiple scans and higher laser power causing a significant rise in temperature in both cooling conditions. Edge effect was very less in case of forced cooling condition. Furthermore, it has been observed that the ultimate tensile strength and micro-hardness in the irradiated region increases under forced cooling condition with increase in laser power and with decrease in scan speed. The microstructure showed phase transformation and a more refined grain structure in the forced cooling condition.

Later, in this study, an electromagnetic-force-assisted laser bending setup was developed to enhance the laser forming characteristics of mild steel. During the experimentation, the controlled external force generated by an electromagnet is applied to the free end of the work sheet. The mild steel specimen having 2 mm thickness is used for laser forming operation with the variation of input parameters i.e., laser power, beam diameter and scan speed. Results indicated that laser bending of mild steel with the electromagnetic attraction significantly enriches the performance parameters i.e., bend angle, micro-hardness, tensile strength and microstructure. The experiments indicated that a large bend angle can be obtained by controlling the electric current and air gap between electromagnet and workpiece. The edge effect was very less in case of small air gap and high electric current. Furthermore, it is revealed that the high value of bend angle is obtained at high laser power, smaller beam diameter and low scanning speed. The laser irradiated region had higher micro-hardness and tensile strength at high laser power, smaller beam diameter and low scanning speed. The microstructure analysis indicated that the high hardness might be due to the fine grain structure and phase transformation in the irradiated zone.

Overall, the performance of the laser bending process for mild steel was improved by bottom forced cooling and the application electromagnetic force. The research findings have the potential to revolutionize laser bending processes, benefitting a wide array of industries by improving productivity, precision, and cost-effectiveness while meeting the specific demands for high deformation with good precision.