ABSTRACT

Ultrasonic Welding (USW) is widely used for joining of plastics because it offers advantages in speed, economy and efficiency and is frequently chosen while joining parts that are too complex or expensive to be moulded in one piece. Weld times of less than one second are typical. In USW, the parts to be joined are held together under pressure and are then subjected to ultrasonic vibrations, at a frequency of ~20 kHz. The consequent alternating stresses generate localized heat in the plastic which soften, melt and solidify to form a bond. As compared to other joining processes like hot plate welding, vibration welding and spin welding processes the heat affected zone is minimum in USW. The ‘ultrasonic horn’ is the key tool used for welding and has two main functions: 1) to introduce ultrasonic vibrations into parts being welded and 2) to apply pressure to form a weld once joined surfaces have been melted.

Horn is a specialised tool designed to vibrate in a longitudinal mode at ultrasonic frequencies. Reliable performance of such horns is decided by the uniformity of vibration amplitude at the working surface and the severity of stress developed during loading condition. The horn design engineer must pay particular attention to designing a tool that will

produce the desired amplitude without damaging the horn. Considerable literature is available explaining the dynamics of the horn both analytically as well by finite element methods.

It is observed from literature that not much work has been done to relate the performance of the horn to the welding output i.e. weld strength and also the weld interface temperature. It is also noted that limited work has been reported on design of large horns of complex geometry and the thermo elastic heating effects on the performance of horns. Thus a systematic study is taken up in three phases with the following objectives.

In the first Phase the ‘Study of different horn profiles made of Al alloy’ is taken up. The objectives of this phase are to (a) characterize the dynamic performance of different horn profiles used in the industry and horn profiles from literature and develop a methodology for designing an ultrasonic horn (b) understand the performance of each horn by welding ABS plastic components as each horn has different amplitude which affects the heating mechanism responsible for welding (c) develop a model for temperature distribution for predicting the temperature at the weld interfaces of the plastic components and correlate the weld interface temperature with amplitude of the horn.

In the second phase the ‘Design and optimization of a large tubular slotted horn’ is attempted. The objectives of this phase are to (a) develop a large tubular slotted horn for welding a large industrial component for obtaining uniform amplitude at the face of the horn and formulate an optimization problem using Design Of Experiment (DOE) (b) develop regression equations and graphs from which the dimensions and positions of the slots can be optimized and (c) propose an empirical formula relating the various parameters studied for optimization to the diameter of the horn.

In the third Phase ‘The thermo-elastic heating of horns made of different materials’ is investigated. The objectives of this phase are to (a) evaluate the stress levels due to cycling loading experienced by the horn for different amplitudes and determine the maximum amplitude limit for each horn material for safe operation and (b) develop a model for temperature distribution in the horn for predicting the thermo elastic heating effects and estimate the safe working temperature of the horn. Different materials have different thermo elastic behavior and hence different stresses/temperatures at their nodal regions.

Based on the objectives a methodology is formulated to carry out the research work. In the first phase different horn profiles (Catenoidal, Gaussian, stepped, Bezier and cylindrical) have been characterized in terms of their dynamic behavior. The dynamic characteristics are the natural frequency, displacement amplitude and the von Mises stresses of the horns. Standard ABS plastic parts are welded using these horns. The displacement amplitude of the horns is correlated to the temperature at the weld interface and the weld strength of the joints. In the second phase of the study, a large horn of complex geometry is designed for welding an industrial thermoplastic component. The position and dimensions of the slots are critical in achieving the desired longitudinal mode with uniform amplitude at the horn face. The DOE is adopted to optimize the position and dimension of the slot. In the third phase, thermo elastic behavior of horns made of different materials is studied. Further, the stresses experienced by the horn under cyclic loading for different input amplitudes is evaluated using ANSYS and the maximum amplitude limits for the safe working of different horn materials are determined. The thermo elastic heating of the horns for various amplitudes is predicted using the software COMSOL. The actual temperature developed in the horn is captured using Infrared camera and compared to the simulated results.

Thus, a systematic study which connects horn profile, displacement amplitude, stresses, temperature at the weld interface and safe stress limits for the horn under cyclic loading is attempted. These findings can be utilized by the industry.