EXPERIMENTAL AND THEORETICAL INVESTIGATIONS ON ULTRASONIC INSERTION PROCESS FOR MANUFACTURING APPLICATIONS

Increasing the usage of plastics in various fields of engineering necessitated the suitable technique for joining the metallic parts with plastic components. When the plastic parts are joined by self-tapping screws or bolts, it may get damaged due to plastic creep. In this circumstances, a technique is needed which has to join the plastic components without degrading them. Many techniques are available to join the plastic components with metal inserts like pre-moulding, cold pressing, thermal insertion and ultrasonic insertion. One of the preferred techniques is ultrasonic insertion process, because of shorter cycle time, minimum induced stress and automation possibilities for mass production.

Ultrasonic insertion is the process of embedding an internally threaded metal insert into the thermoplastic component. In this process, metal insert is placed on pre-moulded hole in the thermoplastic component which is lesser in diameter than metal insert. The ultrasonic vibration produced from horn presses and transfers the ultrasonic energy to the metal insert. Friction between the metal insert and thermoplastic component generates heat energy which softens the thermoplastic component for encapsulating the metal insert to produce the joints. Metal inserts are the mechanical fasteners which are used to assemble and disassemble the components with other parts. Inserts provide resistance to both axial and angular movement by endow with knurls, grooves and undercuts on the external surface of the insert. The dimensions of pre-moulding hole in which metal insert to be encapsulated are determined by functional requirements of the joints.

Ultrasonic horn or sonotrode is a designed tool in ultrasonic system to vibrate in the longitudinal mode at ultrasonic frequencies. Performance of the horn depends on the dynamic properties such as amplitude of vibration, temperature at joint interface and stress developed during loading conditions. So, a horn has to be designed for ultrasonic system which produces the required amplitude of vibration without inducing more stress.

From the literature review, it was understood that ultrasonic solid horns and slotted block horns have been modelled and experimentally validated their performance by measuring displacement amplitude. Ultrasonic joining process parameters were optimized by traditional and non-traditional optimization techniques. Based on the literature review, it was concluded that there is enough scope to carry out the research in the field of ultrasonic insertion of metallic parts with plastic components. Also, it is observed that no work has been reported on design and optimization of block horns using non-traditional optimization techniques. So, a systematic study has been carried out to investigate the influence of process parameters such as horn profile, pressure, inserting time and holding time to achieve maximum pull-out strength and stripping torque using suitable optimization techniques.

This work was divided into three important phases. In Phase I, 'Design and optimization of solid horn profiles' was attempted. In the second phase, 'Parametric optimization of ultrasonic insertion process was taken up. In the third phase, 'Design and optimization of slotted block horn for an industrial component' was attempted.

In Phase I, brass insert and thermoplastic test specimens were designed as per the design specifications and fabricated. Various profiles of solid horn (cylindrical, stepped, Bezier and catenoidal) were analyzed in terms of dynamic characteristic namely natural frequency, amplitude of vibration and von-Mises stress using FEA. Thermal analysis was performed to predict the temperature at joint interface for each profile using ANSYS. Based on the results obtained from FEA, various profiles of solid horns were fabricated with Aluminium alloy (AA6351) and temperature developed at joint interface was measured by conducting experiments. Pullout strength of the joints was tested using computerized tensile testing machine. The displacement amplitude of various horns was correlated with temperature at joint interface and pull-out strength. Based on the results suitable solid horn profile was selected for conducting experiments to optimize the ultrasonic inserting parameters in phase II.

In Phase II, trial experiments were conducted to identify the working range of inserting parameters (Pressure, Inserting time and Holding time). Experiments were designed and conducted as per central composite design using optimal horn profile obtained from Phase I. Pullout strength and stripping torque of joints were measured using computerized tensile testing machine and torque testing machine respectively. Second order mathematical models for pull-out strength and stripping torque were developed using RSM. The predictability of response surface models and significance of insertion parameters were found using Analysis of Variance (ANOVA). The optimum combinations of inserting parameters for maximizing output responses (pullout strength and stripping torque) were obtained by coupling second order mathematical models obtained from RSM with GA as fitness function.

In Phase III, slotted block horn for an industrial component was designed and analyzed using ANSYS to find dynamic characteristics of horn. Uniform amplitude at output face of the horn was improved by optimizing slot dimensions; number of slots and slot location using RSM and GA. Thermal analysis was performed using FEA to predict the temperature at joint interface for optimized dimensions of the slotted block horn using Aluminium alloy (AA6351). Slotted block horn was fabricated for optimized dimensions and experiments were conducted to validate the optimal design of slotted block horn by measuring the temperature at joint interface.

Based on the results from phase I, among the four profiles Bezier horn yields highest temperature at joint interface. Even though temperature obtained for Bezier horn was maximum, pull-out strength of joint was less compared to stepped horn profile. The reason may be excessive temperature at joint interface makes the plastic material to melt and deposit at the bottom of hole instead of settling around the external features of the metal insert. In phase II, optimal ultrasonic inserting conditions were obtained using RSM-GA integration technique; two conditions were randomly selected and verified with validation experiments. Validation experiments show a good agreement with predicted values of responses with less than 5% of error. In phase III, optimized slotted block horn was fabricated using Aluminium alloy (AA 6351) and confirmation experiment was carried out. It was found that predicted temperature correlates well with temperature measured from experiments. This shows that the proposed RSM-FEA-GA integration technique is effective.

This study can provide connection among the horn profile, displacement amplitude, stress developed in horn during loading conditions, temperature at joint interface, design of metal insert, design of thermoplastic component and insertion parameters. Findings from these research work can be helpful to the industries those who are using ultrasonic insertion process for manufacturing of pump casing, mobile phone covers, door panels, electrical switch boxes etc.