EXPERIMENTAL STUDIES ON STRENGTH OF ULTRASONICALLY WELDED JOINTS OF COPPER WIRE AND SHEET USED FOR ELECTRICAL CONTACTS

A THESIS

Submitted by

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ABSTRACT

Recent technological developments in producing electrical contacts are evolving at a fast rate, resulting in consistent functioning of wide variety of customer durable products. Due to advent of component miniaturization and improvement in manufacturing light weight portable products, there exists a significant demand for superior quality electrical contacts. The electrical and electronic components used in these products are subjected to severe operating conditions during the service life of the products. Ultrasonic metal welding (USMW) has received significant attention in the past few years, and has become more reliable and suitable process for producing defect free electrical contacts to be used in these products.

USMW is an environmentally friendly and rapid solid state joining process in which similar or dissimilar metals are joined by the application of ultrasonic vibrations and adequate pressure at the interface. The high frequency relative motion between the parts to be welded result in progressive shearing and plastic deformation between surface asperities. This rubbing action disperses oxides, contaminants and form a sound metallurgical bond between the two metallic parts.

Even though ultrasonic metal welding was invented 70 years ago, a comprehensive understanding on the basic mechanism of formation of joint is far from complete. This lack of understanding is predominantly evident as it relates to the fundamental mechanics of the weld and the correlation of weld mechanics to the overall dynamics of the USMW system.

Copper is mostly used by electrical and electronic industries for making electrical contacts due to its excellent electrical and thermal properties. Therefore, metallic specimens (wire and sheet) made of copper are used in this study.

From the literature survey, it is evident that the ultrasonic metal welding is a process of substantial interest to numerous segments of manufacturing sector and there is enough scope to conduct research in the area of ultrasonic metal welding. The scope of USMW as applied for making an electrical contact comprising of a metallic wire and a flat metallic sheet such as terminal plate or lead tab is of significant requirement in wide variety of applications and the literature review reveal that only limited amount of work is reported in this domain.

A pilot study is carried out using a conventional lateral drive ultrasonic metal welding machine (2.5 kW, 20 kHz) to obtain the useful range of process parameters (clamping pressure, amplitude of vibration of the sonotrode and weld time) and part dimensions (diameter of wire and thickness of sheet). The observations of pilot study revealed the maximum and minimum values of process parameters, part dimensions and the need for design modifications in the existing conventional standard sonotrode to overcome limitations such as part sticking with sonotrode, excessive part deformation and improvement in strength of the joint.

The significant problem confronted by the industries using ultrasonic metal welding process is inferior joint quality and strength of the joint. The design of sonotrode play a vital role in producing quality joints. The primary function of the sonotrode is to vibrate at a level required for joining and to transmit the vibration energy to the point where joining of metals takes place. For producing quality joints, the vibration energy is to be transmitted to the interface without much loss. A study on designing a stepped sonotrode used for joining metallic wire and metallic sheet is carried out using modal and harmonic analysis. Two types of sonotrode are considered in this study. Type I is the existing standard stepped sonotrode with dissimilar cross section and abrupt change in cross section. Type II is the modified stepped sonotrode with similar circular cross section and gradual change in cross section using a tapered profile at the middle of the sonotrode. The dynamic characteristics such as amplitude gain and von Mises stress of Type II sonotrode is compared with the existing Type I sonotrode. The results from analysis reveal that the Type II sonotrode has higher amplitude gain and the von Mises stress level is reduced by 57% when compared with that of Type I sonotrode. The performance of the sonotrodes is evaluated by conducting experimental trials. Based on experiments, it is found that the strength of the joint in tension obtained by Type II sonotrode is improved by 37% when compared with that achieved by Type I sonotrode.

The Type II sonotrode is further used for carrying out experimental trials. Apart from design of sonotrode, usage of optimum combination of process parameters and basic understanding on influence of process parameters and part dimensions on strength of the joint play a significant role in producing defect free joints.

Experimental trials are carried out to determine the optimum combination of process parameters for maximizing strength of the joint under tensile loading and T-Peel loading using Taguchi's method. The three factors (at three levels) considered in this work are the clamping pressure (2 bar, 3 bar and 4 bar), amplitude of vibration of the sonotrode (30 µm, 42.5 µm and 57 µm) and weld time (2 seconds, 2.5 seconds and 3 seconds). Based on initial experimental trials, the metallic specimens with maximum part dimensions of 1.6 mm diameter of wire and 0.3 mm thickness of sheet are used in this study. The strength of the joints under tensile loading and T-Peel loading is determined using a 10 kN tensile testing machine. The factors such as the clamping pressure, amplitude of vibration of the sonotrode and weld time contribute 34.45%, 30.12% and 22.03% respectively to the variations observed in strength of the joint under tensile loading and 30.13%, 22.93% and 18.47% respectively to the variations observed in strength of the joint under T-Peel loading. The optimum combination of process parameters for maximizing strength of the joint under tensile loading and T-Peel loading is identified as the clamping pressure of 2 bar, amplitude of vibration of the sonotrode of 57 µm and the weld time of 2.5 seconds. The factors such as clamping pressure, amplitude of vibration of the sonotrode and weld time have significant effect on strength of the joint.

Experimental trials are carried out based on response surface method to understand the influence of part dimensions along with significant process parameters on strength of the joint under T-Peel loading. The part dimensions such as diameter of wire and thickness of the sheet used in this study are varied at three levels. The three levels of diameter of wire considered are 0.9 mm, 1.2 mm and 1.6 mm and the levels considered for thickness of the sheet are 0.1 mm, 0.2 mm and 0.3 mm respectively. The surface and contour plots developed for various combinations of process parameters revealed the effect of process parameters and part dimensions on the strength of the joint under T-Peel loading. A regression equation is developed for prediction of strength of the joint under T-Peel loading. The results predicted by the regression equation are in good agreement with results from experiments.

Simulation of temperature distribution at the interface is carried out using finite element analysis. The measurement of clamping force, area of deformation and temperature at the interface are carried out using suitable instrumentation. Heat flux due to deformation and friction is calculated and provided as input load for simulation of temperature distribution. The results of temperature obtained from simulation are found to be in good agreement with the results of temperature from experiments measured using thermocouple. An attempt is made to observe the relation between temperature at the interface and strength of the joint in tension. The strength of the joint correlate well with the temperature developed at the interface indicating that the temperature has a significant effect on strength of the joint.

Thus, a systematic study comprising of design of stepped sonotrode, optimization of process parameters for achieving maximum strength of the joint under tensile loading and T-Peel loading using Taguchi's method, influence of process parameters and part dimensions on strength of the joint under T-Peel loading using response surface method and simulation of temperature distribution at the interface using finite element analysis is presented. The findings from this study can provide valuable inputs to the industries using ultrasonic metal welding process.