STUDY OF TEMPERATURE PROFILE IN NUCLEAR FUEL ELEMENT END CAP RESISTANCE UPSET WELDING USING ANALYTICAL TECHNIQUE

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INTRODUCTION

Resistance welding is a group of welding processes wherein coalescence is produced by the heat obtained from resistance of work to the flow of electric current in a circuit of which the work is a part and by the application of pressure [1]. The solid-state upset welding process is essentially the coalescence of two solid surfaces without melting. The radioactive fission materials are encapsulated inside thin wall Zircaloy-4 clad tubes in nuclear industries with the help of two Zircaloy-4 end caps resistance upset welded on both sides. These weld joints are considered as the first barrier for preventing the highly radioactive fission products release into the reactor system and they has to perform satisfactorily under high pressure, temperature and radiation environment [2]. Because of the stringent functional requirements, end cap welding process is considered as the most critical operation in the entire nuclear fuel manufacturing process. The weld joint deformation and microstructures are linked to the peak temperature and cooling rates experienced by it during the welding process [3]. The temperature distribution occurring during resistance spot welding of composite materials was studied by Warren Rice et al [4] considering one dimensional energy flow path with full accounting of heat conduction and energy generation within the materials, at the electrodes and at the contact interfaces of the materials. The equations resulting from the analysis are solved by digital computers for several cases of the welding of nickel, kovar, copper and stainless steel composites such as occur in the semiconductor fabrication processes. N.F.H. Kerstens et al [5] studied the heat distribution in resistance upset butt welding of wheel rim manufacturing process where the modeling of the welding process was done using Marc-Mentat code. The temperature profiles were measured using a FLIR Thermo-Vision A40M thermal camera and point measurements at the welding interface were done with standard 0.25 mm. diameter K-type thermocouples. Ta-chien sun [6] studied the behavior of contact resistance at the faying surface in resistance spot welding of aluminum alloys. The a-spot contact model is utilized in the numerical model to define a relationship for varying contact interface area and a generic equivalent electrical contact resistivity vs. temperature relationship is established using the Wiedermann-Franz-Lorentz law.

RESULTS AND DISCUSSIONS

A decoupled mechanical and electrical analysis is performed using ANSYS parametric design language to predict the contact interface area and contact resistance variation with bulk material temperature during resistance welding of Zircaloy-4. The contact resistance values for Zircaloy-4 as obtained are compared with normalized values of contact resistances computed using formulas and material properties for Zircaloy-4 from various literatures up to 500°C. A good correlation is observed between the numerical and theoretical results, which suggest the effectiveness of numerical modeling in predicting electrical contact resistance. Similar variations of contact resistances are assumed for higher temperatures as obtained with theoretical computations. An analytical transient heat transfer study is performed next to predict the peak temperatures in the welding process with pre-defined welding parameters. The results of peak temperature obtained using analytical procedures are verified using thermal imaging technique. Since the end cap welding takes place inside a closed chamber with small inside diameter (around 80mm.), a non-contact type measurement is the only feasible technique to record temperatures during welding. An FLIR P640 thermal camera is used to capture images during the welding process. The process of multiple trials is repeated with pre-defined welding parameters and the recorded temperatures with thermal camera are plotted with welding time. The results obtained with thermal imaging showed similar trends with analytical transient heat transfer study results as shown in figure 1. However, the recorded values are much lower and a maximum difference of about 20% with respect to recorded values are observed at low pre-heat currents due to the external heat losses during welding, which were not taken into account in analytical model. The temperature measurements by thermal camera FLIR P640 is also not very accurate due to its limited frame rates. With the use of...
photo-sensors with lower response time and by placing them inside the welding chamber in end cap welding machine, more accurate results can be obtained in future.

CONCLUSIONS

The temperature distribution in solid-state end cap welding process is predicted using analytical heat transfer study and the results are verified using thermal imaging technique. The predicted and actual temperature rise with welding time showed similar trends. The temperature rise occurs at much faster rate in the initial phase due to high initial contact resistance between cladding tube and end cap. The peak temperature in the welding process for the current ranges of welding variables reaches around 850°C-900°C under normal operating conditions, which supports the presence of Widmanstatten or martensitic structures at the heat affected zones in end cap welding. However, more accurate measurements of the temperature are possible in future with the use of photo-sensors with very low response time.

REFERENCES