INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
SHORT ABSTRACT OF THESIS

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SHORT ABSTRACT

End forming of tubes generally refer to making of simple or complex shapes such as expansions, reductions, flares, flanges, tapers, and beads made at the end of the tube by single or multiple metal forming operations. These end formed tubes have plenty of applications in our day-to-day life, agriculture and automobile sectors.

Earlier research in the field of tube end forming was focused on identification of main process parameters, especially tube inversion methods. With the further advancement of tube end forming technology some innovative methods of joining involving tube end forming have been proposed and it was observed that joint strength of end formed joints is at par with the joints obtained from conventional methods.

Tubes are manufactured mainly from two ways. First is extrusion from metal billet and second from welding. Though there is always a debate over the strength of welded tubes and seamless tubes, welded tubes have other advantages. Welding of tubes are possible in large diameter and thinner walls. It has been observed that friction stir welding (FSW), invented in 1991 in TWI (UK), became popular for welding of low melting point alloys such as aluminium and magnesium because of its inherent advantages over other welding processes. Friction stir processing (FSP) has been developed later on, which is aimed to modify microstructures and properties in the processed region of a single workpiece rather than joining two metal pieces.

In this context, joining using end forming and end forming of joint (FSPed) tubes are conducted in the present thesis work. In the first part, tube end forming operations has been studied through mechanical joining operations such as a tube to a sheet or a tube to a tube. FE simulation software ABAQUS explicit has been used for this purpose. Effect of important process parameters affecting the joint quality has been examined through load-displacement behaviour and thickness evolution. A number of criteria have been proposed to decide the quality (successful or unsuccessful) of the joint. Later, the proposed joining methods have been experimentally demonstrated through some selected cases. A good match between experimental and numerical load evolution curves has been observed in case of tube-tube joint, while in case of tube-sheet joint a difference in load is observed after neck formation. It is felt that in this case (tube-sheet) joint failure criteria needs to be incorporated in the numerical model to improve the accuracy of the predicted result.

Mechanical testing of end formed joints (tube-sheet and tube-tube) has been conducted and their strength has been compared with conventional gas welded joints. The effect of inclination has been studied on the strength of tube-sheet joints. End formed joints perform well on flat dies while welded structures perform well on inclined planes. In case of tube-tube joints, end formed joints proved to be better in strength as compared to welded structure in pull-out test, while in compression test the strength of end formed joint is at par with the strength of welded structure.

The second part of the thesis is aimed at end forming operations of friction stir processed (FSPed) AA 6063-T6 tubes at different process parameters. In this context, the effect of tool rotational speed, tool traverse speed, tool pin profile and tool plunge depth has been studied during processing and end forming operations. The end forming operations conducted are expansion, reduction and beading. The effect has been seen in terms of, load evolution of processed and unprocessed tubes, hardness variation along the processed zone before forming and after forming, and energy absorbed in processed and unprocessed tubes during end forming operations at different process parameters and their levels. Grain size measurement and dislocation density measurement into different zones of processed region has been done. At last, end-forming simulations have been conducted with an aim of minimizing the experimental efforts. In this context, load evolution and instability prediction for processed as well as unprocessed tubes have been accomplished during different end forming operations.

From the present investigation, it has been observed that formability of the FSPed zone improves after FSP in many cases, while flow strength decreases for different cases with respect to base metal. Hardness decreases in the FSPed zone after FSP, while increases after end forming. The decrease in hardness is due to heat experienced in the process of FSP while increases is due to strain hardening during end forming. The microstructural examination of the processed zone confirms three different regions in the processed zone based on grain size. The variation in recrystallization process and plastic deformation is responsible for such variation in grain size in processed zone. In addition, it has been observed that for different process

parameters except few cases, FSPed zone having lower density results in larger *n* value as well as ductility.

Parent tube needs larger load to deform as compared to processed tubes during different end forming operations and process parameters. A larger strength of base metal as compared to FSPed zone is responsible for this. Within FSPed tubes made at different levels and process parameters, maximum load obtained during load evolution depends mainly on strength of the FSPed zone except few cases such as during expansion and beading in case of rotational speed, and in expansion process for different plunge depths. In these cases, maximum load occurrence during load evolution depends on initial hardness and particularly on hardness index, *H*. FSPed zone experiences larger thinning as compare to base metal in case of expansion and finally failure occurs at the middle of the FSPed zone. FSPed zone having larger ductility has thinned more. In reduction, FSPed zone experiences larger thickening as compared to corresponding base metal zone. Wrinkling and overlapping are observed in FSPed zone during reduction. A softer FSPed zone as compared to base metal zone is responsible for these phenomena. FSPed zone having lower flow strength has thickened more for different process parameters in reduction. In case of beading, base metal thickening is more than FSPed zone thickening in most of the cases. Relative strength of FSPed zone and base metal zone as well as respective strain hardening exponent '*n*' is responsible for this. Here fine cracks are seen at the peak bulged height of the base metal region. Larger hardness and reduced ductility of the base metal as compared to FSPed zone is responsible for this.

Beading absorbs larger energy for raw and FSPed tubes among conducted end forming operations, while in expansion lesser energy is observed. In expansion, parent tube absorbs larger energy as compared to FSPed tubes. In reduction, energy absorbed by FSPed tubes is comparable with parent tube, while in beading energy absorbed by FSPed tubes is larger than that of the parent tubes in most of the cases. Larger energy absorbed in case of FSPed tubes with lesser load requirement make the processed tubes an appropriate choice for energy absorbing devices in aircraft and shipbuilding industries in place of raw tube.

In most of the cases in expansion and reduction a closer comparison between experimental and prediction data is observed with respect to load evolution. In beading, a significant difference in load-displacement data is observed, when experimental and predicted results are compared. With respect to instability occurrence results obtained in reduction and beading compared well between experiments and prediction for different cases, while a difference is seen in most of the cases in expansion. Modeling conditions, particularly strain rate and friction coefficient mismatch are responsible for such a difference.