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Entitled

STRUCTURAL INTEGRITY ASSESSMENT OF SHELL AND TUBE HEAT EXCHANGER TUBE-TO-TUBESHEET JOINTS FABRICATED USING CONVENTIONAL AND NONCONVENTIONAL MANUFACTURING PROCESSES

By

Dinu Thomas Thekkuden

Faculty Advisor

Prof. Abdel-Hamid Ismail Mourad, Mechanical and Aerospace Engineering Department

College of Engineering

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Abstract

Tubes and tubesheets, integral components of shell and tube heat exchangers, have an important role in the functioning of the heat transfer between the tube-side and shell-side fluids. Tube-to-tubesheet joints act as a barrier to prevent the mixing of the transfer fluids in addition to aiding the structural rigidity of the shell and tube heat exchanger. Tube expansion process and welding are the manufacturing processes used for fabricating structurally rigid tube-to-tubesheet joints. Many instances of tube-to-tubesheet joint failures leading to the complete collapse of the heat exchangers demand attention to assessing the mechanical and metallurgical characteristics of tube-to-tubesheet joints fabricated using conventional manufacturing processes (tungsten inert gas welding and roller tube expansion). The possibilities of novel non-conventional techniques for joining tube and tubesheet are highly demanded to overcome the disadvantages of conventional manufacturing processes. The main objectives of this work are to investigate the structural integrity of tube-to-tubesheet joints produced using conventional manufacturing processes involving tungsten inert gas (TIG) welding, roller expansion and hybrid TIG welding-roller expansion and, non-conventional processes involving friction stir welding (FSW) and hybrid roller expansion-FSW. This dissertation initially investigated and compared the performance of TIG welded, roller expanded and hybrid TIG welded-roller expanded low carbon steel-based A179 tubes to SA 516 Gr. 70 tubesheet joints at different expansion percentages (4%, 6%, 8% and 10%) and tubesheet groove conditions (without groove, one groove and two grooves). Secondly, the effect of tube expansion percentages in hybrid TIG welded-roller expanded A179 tube to SA 266 Gr.2 tubesheet joints at 3%, 5% and 7% expansion using mock-up tubesheet block with multiple holes for accommodating the influence of neighbour hole expansion is assessed. Furthermore, comparative studies are made by evaluating tube pull-out load, minimum leak path, hardness, and weld metallurgy in accordance with international standards. The microstructural changes and hardness at the expanded and transition zone were given essential attention since defects are known to nucleate at the transition and expanded regions. As an alternative to conventional techniques, the scope for the unconventional fabrication of AA 6061-T6 tube to AA 6063-T6 tubesheet joints using the friction stir welding process is further analyzed. The effect of tube projection and radial clearance on the mechanical and metallurgical characteristics of friction stir welded joints are investigated using a hybrid integrated Taguchi-PCA-GRA optimization technique. Finally, a novel technique for producing hybrid joints using roller expansion followed by friction stir welding on AA 6061-T6 based tube and tubesheet is proposed. The results of the dissertation proved that the roller expansion process alone is insufficient for relatively less thick tubesheets (23 mm tubesheet) and either TIG welding or hybrid joining (TIG welding + roller expansion) is mandatory for producing quality joints with adequate pull-out strength. Poor workmanship, lack of weld penetration and insufficient minimum leak path reduced the strength of the joint significantly. Tubesheet thickness and roller expansion length were proven as crucial factors in providing the tube pull-out strength. The grains at the expanded and transition zones were significantly refined by the roller expansion process. The qualified tube-to-tubesheet joints (satisfactorily tested) exhibited joint strength greater than the axial strength of the tube. In the case of friction stir welding of tube-to-tubesheet joints, high weld penetration and maximum leak path were achieved using an effective selection of tube projection and radial clearance compared to the tungsten inert gas welding process. Furthermore, the study significantly contributed to the proposal of producing hybrid roller expanded-friction stir welded joints where friction stir welding was proved efficient for sealing the roller expanded joints. The outcomes and techniques of the study are highly beneficial to the professionals and researchers working in the fields of heat exchangers and boilers.

Keywords: Tube, tubesheet, tube-to-tubesheet joint, low carbon steel, roller expansion, tungsten inert gas welding, friction stir welding, weld metallurgy, microstructure, tube pull-out load, minimum leak path.