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Entitled

FRICTION STIR WELDING OF TUBE-TO-TUBESHEET AND SPOT JOINTS FOR VIRGIN AND RECYCLED THERMOPLASTIC MATERIALS.

by

Syed Haris Iftikhar

Faculty Advisor

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

College of Engineering

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Abstract

Thermoplastic materials are becoming popular, due to their chemically inert and anti-fouling properties, for use in industrial heat exchanger applications involving heating/cooling of highly reactive fluids like acids. A novel non-conventional joining framework, based on the friction stir welding (FSW) technique, is developed to create high-quality thermoplastic tube-to-tubesheet joints (TTJs). The proposed technique has applications in the thermoplastic shell-and-tube heat exchanger and piping industries (as flange-to-pipe joints). The primary objective is to study the feasibility of the FSW technique for developing thermoplastic TTJs, followed by optimization of the process parameters and detailed material characterizations. This work used workpieces (tube, tubesheet) made of carbon black reinforced high-density polyethylene. The effect of different FSW parameters (dwell time, plunge depth, rotational speed, and tube protrusion) on the tube pull-out behavior was studied. The FSW technique showed capabilities at a wide range of operating conditions. The macroscopic and microscopic (SEM-based) fractographic studies suggest that the FSW joints can fail in a ductile, brittle, or mixed manner, depending on the FSW conditions used. The DSC results showed no significant crystallinity changes of the weld material. The TGA results showed no significant thermal degradation of the weld material. The FTIR analysis indicated possible oxidation of the weld material. The capability to form TTJs with high leak path, high load bearing capacity, and no significant material degradations makes the FSW technique suitable for thermoplastic shell-and-tube heat exchanger applications.

Further, as a second objective, the effect of adhesive reinforcement and radial clearance (RC) on the development of FSW-based thermoplastic tube-to-tubesheet hybrid joints (TTHJs) was investigated. The FSW technique provides higher load bearing capacity (326 N (0.0 RC), 517 N (0.5 mm RC)) than adhesive joints (226 N (0.0 RC), 206 N (0.5 mm RC)). For 0.0 RC, the adhesive reinforcement improved the load bearing capacity of hybrid joints by 15.6% compared to FSW joints. On the contrary, for 0.5 mm RC, the adhesive reinforcement negatively impacted the load bearing capacity and reduced it by 40.6%. The FSW technique with 0.5 mm RC provided a higher leak path (along with a high load bearing capacity) of 77% remaining tubesheet thickness (> tube thickness) compared to that of 46.6% (< tube thickness) achieved at 0.0 RC. However, the adhesive reinforcement can enhance the leak path of 0.0 RC FSW joints to around 100% remaining tubesheet thickness (> tube thickness) by introducing the adhesive material at the tube-sheet interface.

There is also a real demand for sustainable lightweight thermoplastic structures (like thermoplastic heat exchangers) because of growing environmental concerns. One important solution is developing structures through recycled scrap/waste thermoplastic materials. As a third objective, the lap-joint configuration friction stir spot weldability of recycled thermoplastics was studied, to help with analyzing the potential of friction stir-based welding techniques towards developing these sustainable structures. The combined behavior of recycling-welding procedures is investigated, as they may cause degradations; to ensure that the base thermoplastic polymer's chemical, thermal, and mechanical properties are retained. In this work, scrap laban bottles made from HDPE material are used. The highest lap-shear load of 1528 N was achieved at the optimum welding conditions of 1600 rpm rotational speed, 1 mm plunge depth, and 60 s dwell time. Fractographic studies (macroscopic and SEM-based) suggested four types of fracture morphologies depending on welding conditions used. The DSC results showed no significant differences in melting temperature and crystalline content of the polymeric material. The TGA tests showed no significant thermal degradations. The FTIR analysis of all the samples (bottle, recycled sheet, weld material) exhibited characteristic HDPE peaks. All these results suggest that combined welding-recycling processes had a minimal impact on the polymeric structure. Thus, friction stir spot welding (FSSW) technique joins recycled thermoplastic scrap/waste materials with high lap-shear load and without any significant polymer degradations.

Keywords: Friction stir welding, friction stir spot welding, heat exchangers, high-density polyethylene, hybrid joints, polymers, recycling, thermoplastics, tube-to-tubesheet joints