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Microstructure and mechanical properties of friction stir processed cast Eglin steel (ES-1)

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Abstract

Eglin steel, an ultra-high-strength steel developed for various demanding applications, is a low-cost alternative to 4340 steel, in which nickel and cobalt additions are replaced by higher tungsten additions, thereby achieving comparable strength and ductility. Friction stir processing (FSP) was carried out on this steel under two heat input conditions, which fell above the A_3 transformation line. Microhardness values along the horizontal and vertical directions of the processed region cross section were reported for the lower heat input condition, and correlated with corresponding microstructures. A 3D heat transfer and material flow model was used to predict the peak temperature and cooling rates in these zones. Site-specific tensile tests of specimens extracted from the top to the bottom of the stir zone (SZ) showed ultimate tensile strength (UTS) greater than 2 GPa, with a total elongation close to 10 % at ~ 4 mm from the top surface of SZ. Transmission electron microscopy (TEM) analysis of the high strength location showed microstructure consisting of nano-twinned martensite and nano-bainite laths of size ranging from 200 nm to 300 nm, and confirmed the existence of retained austenite. This mixed microstructure was comprised of finer aggregates of martensite, bainite and retained austenite, which were postulated to be responsible for the high strength and ductility combinations.

Key words: *Friction stir processing; Eglin steel; mixed microstructure; nano-twinned martensite; nano bainite; site-specific tensile properties*

1. Introduction

Eglin steel has been developed recently for various high strain rate applications [1] as a cost-effective replacement for high-strength steels such as AerMet100, HP 9-4-20, HP 9-4-30, and AF 1410, which use costly Co and Ni additions. This novel alloy has been utilized for a wide range of applications, including missile parts, tank bodies, and machine parts. The patent document for this material [2] mentions the addition of various alloying elements, including silicon to prevent cementite precipitation (which is sluggish at tempering temperatures used for Eglin steel). Other additions include vanadium and nickel to promote toughness, chromium to enhance strength and hardenability, molybdenum to improve hardenability, and tungsten to add elevated temperature strength and wear resistance. For various performance-related applications of this alloy, a combination of high strength and ductility are indispensable. Details of friction stir welding (FSW), a solid-state joining process developed by The Welding Institute (TWI) in 1991, are well-documented [3]. The outstanding success of this process to join various aluminum, magnesium, and copper alloys [4][5][6][7] naturally lends itself to exploration of steels, which are regarded as the most widely used structural materials. However, FSW applicability has been

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