Friction stir welding of ductile iron and low carbon steel

C.-P. Cheng*,1, H.-M. Lin2 and J.-C. Lin3

Friction stir welding (FSW) is a low distortion, high quality solid welding. There is no melting during the welding process, which results in improved welding quality. Ductile iron has the advantages of being low cost, of excellent castability, and of being good mechanically. Therefore, it is generally used in many structural engineering parts. In this study, ferritic ductile iron and low carbon steel were used to explore the qualities of dissimilar metal welding under different conditions. The FSW process, changes in the microstructure of the welding area and the mechanical properties of joints were explored. According to the research, we found that when dissimilar metal welding is conducted at 982 rev min$^{-1}$ with a travelling speed of 72 mm min$^{-1}$, flawless welding quality can be obtained if the stir rod rotates counterclockwise with carbon steel fixed in the advancing side and with ductile iron in the retreating side. FSW successfully provided defect free welds. However, fine pearlite and martensite structures appear in the stir zone, which result in mechanical property degradation of weldments. The stir zone in the weldments is very hard due to martensitic transformation. After heat treatment, the tensile strength improves, and the fracture site appears in the base metal of the carbon steel. However, the welding nugget is not completely filled when the stir rod directs ferritic ductile iron to the advancing side in the clockwise direction and carbon steel in the retreating side, which results in defects and lower welding quality.

Keywords: Friction stir welding, Ductile iron, Carbon steel, Dissimilar metal welding

Introduction

Because of its excellent castability, good mechanical properties and low cost, ductile iron has been generally used in many structural engineering parts.1 Moreover, the strength, hardness and other mechanical properties of ductile iron can be changed by controlling its microstructure to meet various application requirements. The biggest obstacle to use ductile iron is its welding properties. Since ductile iron contains much more carbon than common carbon steels, carbon will spread into the melting iron during fusion welding, forming a high carbon melt. Rapid solidification then forms the hard and brittle cementite structure, which will result in ductility degradation of the weld and other processing problems.2 Some current research aims to eliminate and decrease the chances of hard and brittle phases in solidification areas by preheating or post-annealing, but the effects they produced are limited and unpractical.3 In 1991, The Welding Institute issued friction stir welding (FSW) technology, which is a solid joining method with low distortion, high quality and low cost.4 In FSW, a stir rod is rotated at high speed and inserted into the materials to be welded. Heat from friction creates plastic flow in the materials, allowing them to be welded. The welding temperature is under the melting point of the base metals during the whole welding process. No melting phenomenon appears in the joining parts, so FSW is a solid welding process with pure structural changes. Compared to traditional welding methods, FSW generates fewer defects, has low residual stress, excellent size stability, and undergoes no composition change after welding; it can be applied to hard to melt materials.5,6 Initially, the development of FSW technology mainly focused on aluminium or magnesium alloy,7–13 but recently, there have been some investigations into welding low carbon steel, 12% chromium alloy steel, mild steel, stainless steel and dissimilar metals.5,14,15 Since steel has high hardness and flow stress at elevated temperatures, the welding temperature commonly reaches to 1000°C. Additionally, the stir rod material must have an antiabrasion surface and high temperature stability. Thomas et al. used bobbin technique to design the FSW tool, in which both the top and bottom surfaces of the specimen were controlled. This bobbin tool was used to join 8 mm samples of a 12% chromium steel and produced fine welds.16 Furthermore, these studies have reported that FSW achieves grain refinement in the stir zone. Complex phase transformation has also been shown to occur in the FSW process.17–19

1Department of Mechatronic Technology, National Taiwan Normal University, Taipei 106, Taiwan
2Department of Mechanical Engineering, Far East University, Tainan 744, Taiwan
3Department of Industrial Education, National Taiwan Normal University, Taipei 106, Taiwan

*Corresponding author, email cpcheng@ntnu.edu.tw