SURFACE TREATMENT OF LOW CARBON STEEL BY FRICTION STIR PROCESSING

By

Mohamed Salah Mohamed Newishy

A Thesis Submitted to the Faculty of Engineering at Cairo University in partial fulfillment of the requirements of

Doctor of Philosophy

In

Metallurgical Engineering

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2014

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Acknowledgements

The most important acknowledge is to Allah (God) SWT. I glorify Allah Who creates me, Who guides me, Who provides me with sustenance and whenever I fall ill. It is He Who heals me. May Allah's peace and blessing be upon our beloved prophet Muhammad, his family, his companions and his followers until the day of resurrection.

It is a great pleasure to express my gratitude and indebtedness to my supervisors, Professor Mohamed Rafaat Elkousy, Profssor Nahed Abdel-Raheem and Dr. Morsy Amin for their guidance, encouragement, moral support, and affection through the course of my work. I am also grateful to Professor Hedetoshi Fujii for his support during my experiments by all of his laboratory equipments, his staff support and his hospitality. My special thanks to Dr. Yoshiaki Morisada, Dr. Sun and all staff members of Department of Material Diagnosis and Life Assessment (Fujii Lab.) for their timely help in completion of this work. My thanks also go to all staff of Joining and Welding Research Institute, Osaka University for their patience and helpfulness.

My gratitude also extends to my teachers and staff at the CMRDI of Egypt: Professor Alber Sadek for their kind advice and encouragement. I would like to express my great thanks Dr. Mohamed Mosalam Ghanem and Dr. Saad Abdel-Mohsen for their support. My thanks also go to all staff of Central Metallurgical Research and Development institute (CMRDI).

I wish to acknowledge the financial support given to me by the Cultural Affairs & Missions Sector, Ministry of High Education of Egypt to carry out this research work.

Finally I would like to thank my parents. They raised me, support me, taught me, and loved me. I would like also to thank my brothers and sister for their support and encouragement throughout my life. Especial appreciation and gratitude is given to my wife for her encouragements and patience, for listening to my complaints and frustrations, and for believing in me.

Abstract

An investigation was carried out to evaluate the feasibility of Friction Stir Powder Processing (FSPP) to produce particle reinforced Metal Matrix Composite (MMC) materials. WC and TiB2 ceramic particles with particle sizes of 5 and 2 micron respectively were used as reinforcement particles on annealed JISG3141 SPCC steel sheets. Several strategies for reinforcement and its influence on the particle distribution and homogeneity were investigated. The most promising results were achieved when the pin fully overlapped the covered groove. The use of smaller sized particles led to more homogeneous composite layers and smoother gradients. The mechanisms involved in FSPP also led to severe plastic deformation which in turn promotes the dispersion of the particles within the matrix and resizes the ceramic particles.

2 mm depth surface layer of processed material were produced by multiple FSPP pass. Multiple passes were done clock and anticlock wise respectively to study potential differences on the resulting properties. It was observed that processing in these two conditions led to modified particles distribution and homogeneity, since the processing in different directions homogenate particles distribution in addition to the elimination of the formed defects or voids from the previous passes.

Friction stir processed materials to produce MMC showed localized microstructural modification in addition to the homogeneous ceramic particles distribution results in a gradual hardness and wear properties modification. Very fine equiaxed ferrite grains were obtained after FSP of low carbon steel without any reinforcement. The grain sizes of the nugget zone were analyzed using EBSD, the average grains size decreased from 18 µm for the base metal to 4 µm for the processed nugget without reinforcement. The grain refinement is believed to be due to severe plastic deformation. XRD of the fabricated composite layers showed no evidence for phase transformation or interfacial reactions during the FSPP. TEM analysis showed sound particles/matrix interface with no cracks or interfacial chemical reactions in addition to more grain refinement.

The average hardness of the resulted composites increased to over 600 and 550 HV for steel/WC and Steel/TiB2 composite layer respectively, more than 4 times that of the nugget zone without reinforcement and nearly 6 times the base metal.

The fabricated steel/WC and Steel/TiB2 composite layer exhibited much superior wear resistance against SiC ring than the as-received low carbon steel. Improved wear resistance of the composite layer was explained by the hard and homogeneously distributed ceramic particles. The wear resistance of the steel/WC composite layer is more than that of steel/TiB2 composite layer due to the difference shown in hardness results.

WC-Co severe tool wear was observed and higher grade tools for the future work were recommended.

Chapter 1

1.1 Introduction

Most of the engineering structural components subject to service conditions where mechanical loading may vary within the part. Therefore, the material's structure and properties need to be optimized in order to increase its performance. Metal Matrix Composites (MMCs) generally refer to a kind of materials in which a hard second phase or phases (reinforcement) has been artificially embedded into a ductile metal or alloy (matrix) to combine both merits of ductile metals and hard reinforcements. The industrial interest in MMCs is mainly related to the possibility of controlling the gradation of the physical and/or chemical properties, through microstructural manipulation. Aluminum matrix composites, for example, are advanced engineering materials developed for weight critical application such as aerospace and automotive industries .

Powder metallurgy, Stir casting, infiltration process, spray deposition are some of the most common technologies used to manufacture Metal Matrix Composites. However, these processes are time consuming and expensive, precluding a widespread use of such materials in mainstream engineering applications.

Friction stir processing (FSP) is a relatively new technique for material processing based on the same fundaments as friction stir welding (FSW) that allows local modification and control of microstructures in near-surface layers, for the purpose of improving surface or in volume mechanical properties. A selected area of a material could be modified by a rotating tool inserted into the material to produce a highly plastic deformed zone. The stir zone consisting of both fine and equiaxed grains has excellent hardness and strength.

Recently, FSP has been studied as a less expensive and versatile process to produce surface composites using its intense material stirring to disperse reinforcements into a metal matrix. On the other hand, the intense and relatively unpredictable nature of the visco-plastic material flow in the presence of these dissimilar reinforcements, leads to irregular results and erratic distributions. In addition, the homogeneous dispersion of the fine ceramic particles is also important for increasing its mechanical properties as well as helping to extend the lifetime of different steel parts.

Therefore, there is a worldwide interest to further develop and investigate FSP of steels, and in particular in steels surface modification. Researchers want to meet the consumer's needs to produce composite materials that can withstand the severe circumstances and still have a long parts life. Obtaining such new composite materials through FSP will make FSP of steels technically and economically feasible. As a very promising technology and a very young process, there is still a lack of precise knowledge of the physical interactions involved in friction stir processing. New reinforcing methods such as FSP should be experimented to estimate the future applications and limitations of the process.

1.2 Research objectives

The aim of this work is to study the feasibility of the friction stir processing as a new technique for microstructural modification through the fabrication of a homogeneous surface layer from reinforcement particles composites (WC, TiB2 and hybrid of WC and TiB2) and JISG3141 SPCC low carbon steel. The in details investigation of the processing parameters effects on microstructure homogeneity, hardness and wear properties of the resulted composite material will be carried out to gain clear understand of the friction stir powder processing. Another objective of this study is to understand the material flow phenomenon around the processing tool by considering the WC particles as a tracing material. the following steps was conducted to achieve the target:

1. Design an experimental setup to conduct friction stir processing
2. Develop steel base composites reinforced with micro-sized particles made by friction stir processing.

3. Investigate the effects of rotational and travel speeds on the resulting microstructure of the friction processed material.
4. Modify steel by friction stir processing and compare the difference between the modified steel and steel base composites.
5. Investigate the effect of FSP on the resulting hardness and wear properties of the modified steel and steel base composites.
6. Evaluation of the microstructural characteristics by using XRD, SEM and TEM.

Chapter 2

Literature Review

2.1 Friction Stir Welding

Friction Stir Welding (FSW) is a very important welding process (invented, patented and developed by TWI of UK in 1991), which is a derivative of conventional friction welding, Which enables the advantages of solid phase welding to be applied to the fabrication of long butt and lap joints with very little post weld distortion. These process aspects, namely, tool design, weld microstructure; weld, mechanical properties and many more have been explored extensively by many researchers to better understand FSW process. [1-10]

FSW has been applied to many industrial sectors around the world. The process utilizes a non-consumable rotating tool to generate frictional heat and deformation between the two pieces to be welded. The work piece placed on a backing plate and clamped rigidly with fixtures. Heat is produced due to shoulder surface friction with the top surface of the work piece, which softens the material to be welded. The tool shoulder is the primary means of generating heat during the process. It prevents expulsion of the material and guides the movement of the material during welding. The tool pin is normally one third the diameter of the shoulder extending from the shoulder and rotates with at a speed ranged from hundreds to thousands of RPM. The tool is slowly plunged into the work piece until the shoulder surface touches the workpiece[4-5]. The pin then moves along the area to be welded on the work piece with a specified travel speed. Tool pin is the secondary means of heat generation. The pin of the rotating tool provides the stirring action to the materials of the two plates to be joined. As the tool travels along the path of interest, the weld cools, thereby joining the two plates together. A schematic of FSW process is shown in Figure 2.1. [6]

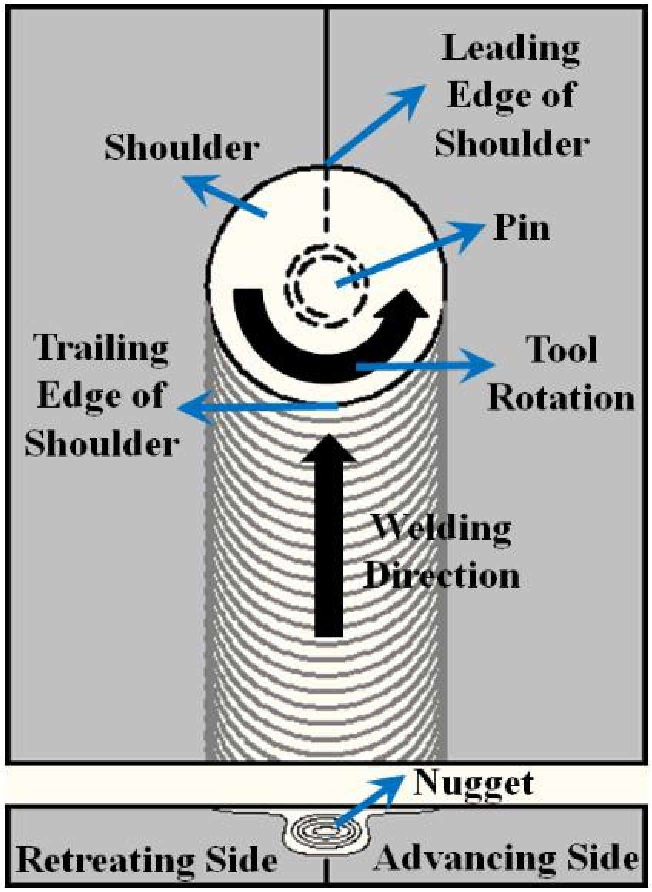

Figure2.1: Schematic representations of FSW process principles. [6]

2.1.1 Friction stir welding process

FSW setup consists of (1) cylindrical rotational tool, (2) two or more work materials of similar or dissimilar material combinations (3) backing plate and finally (4) clamping or holding fixture as shown in Fig. 2.2. The rotating tool design consists of a combination of two cylinders of a specific radius ratio known as shoulder and smaller radius pin or probe, where the height of the pin or probe is usually more than half of the work material thickness but not equal to its overall thickness.[7-9] The materials to be joined may be arranged as conventional welding method, but the most common configurations used in FSW are abutted and lapped configuration. For any configuration, FSW has the capability to join thick plate without the need for special preparation prior to the welding process. Meanwhile, the backing plate is to ensure the establishment of confined volume and it becomes a must when welding with a pin penetration approaching the bottom of the work materials. The most crucial part of the work materials set up is the clamping or holding