Materials Forming, Machining and Tribology

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Coatings

Materials, Processes, Characterization and Optimization

Springer

Materials Forming, Machining and Tribology

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Preface

The editors are pleased to present the book *Coatings—Materials, Processes, Characterization and Optimization* under the book series ***Management and Industrial Engineering.*** Book title was chosen as it depicts upcoming trends in the industrial world for various critical applications. This book is a compilation of different aspects of the same.

Treatment of surface is a established provider of advanced materials processing and coating technologies for a wide range of applications in the automotive, aerospace, oil and gas, semiconductor, missile, power, electronic, biomedical, textile, petroleum, petrochemical, chemical, steel, power, cement, machine tools, construction industries and many more. The development of a suitable high-performance coating on a component fabricated using an appropriate higher mechanical strength metal/alloy offers a promising method of meeting both the bulk and surface property requirements of virtually all imagined applications. This book focuses on the recent developments in the coating processes, sub-processes and emphasizes on processes with the potential to improve performance quality and reproducibility. The book demonstrates how application methods, environmental factors and chemical interactions affect each surface coating's performance. In addition, it provides analysis of the latest polymers, carbon resins and high-temperature materials used for coatings and describes the development, chemical and physical properties, synthesis, polymerization, commercial uses and characteristics for each raw material and coating. The coverage further includes the characterization techniques to select the right ones to solve the coating problems, and optimization study to identify the critical coating parameters would be needed in order to ensure a robust process.

The main objective of the book is dedicated to deal with the interesting field of coatings, preparation and characterization of the same and elaborates on application of optimization techniques for sustainability and effectivity.

In view of the changing scenario, this book has parts providing general introduction, characterization, applications, simulation and optimization towards the subject called *Coatings*. This book will serve as a knowledge databank by providing state-of-the-art descriptions of the corresponding problems and advanced methods for solving them for industrial fraternity.

The chapters in the book have been categorized in **four parts**, namely **Part I: Processes; Part II: Applications; Part III: Characterization;** and **Part IV: Simulation and Optimization**.

Part I contains Chaps. 1 and 2, whereas **Part II** has Chaps. 3 and 4; **Part III** with Chaps. 5 and 6 and **Part IV** contains Chaps. 7 and 8.

Part I starts with Chap. 1 which provides an overview of friction stir processing (FSP). This is a novel way to produce the surface composite coating and also provides a simple solution to enhance the surface properties of the material by producing a surface composite coating over the base material. So, with the application of FSP, various properties like hardness, strength, corrosion, wear, microstructure, etc., can be enhanced. The chapter hence provides an understanding of composite materials and surface composite coatings. The information about FSP and how surface composite coating is prepared by FSP has been discussed in detail. The chapter concludes with the future scope of FSP.

Chapter 2 provides another method for surface treatment and surface modification, i.e. microwave processing. This method apart from being quite effective is also cleaner and environment-friendly. The chapter provides a detailed explanation of microwave heating and its application in the processing of various composites of engineering importance highlighting the suitability of microwaves in joining and surface treatments of materials. The chapter also elaborates on the preparation of ceramics and nano-materials using microwaves. The chapter culminates with a discussion on future perspectives and applications of this technology in processing and fabrication of other engineering materials as coating.

Chapter 3, the first chapter of Part II, enlightens the readers with application of edible coatings and packaging materials for preservation of fruits and vegetables. Fruits and vegetables are particularly perishable commodities as they contain 80–90% of water by weight. Edible coatings are thin films made applied to the exterior surface of a substance, which offers protection against external moisture, oxygen and pathogens. Various components commonly used in the manufacture of edible coatings include polysaccharides, proteins, lipids, composites and resins. The present chapter discusses the use of different edible coatings, preservatives and packing methods as carriers of functional ingredients on fresh fruits and vegetables to maximize their quality and shelf life. Moreover, it also elaborates on recent developments in the application of antimicrobials during packaging to increase the functionality of foods.

Chapter 4 describes corrosion resistance of high-entropy alloys. High-entropy alloys (HEAs) are categorized as alloys containing at least four major elements. This chapter presents a brief account of the formation of high-entropy alloys and corrosion resistance property and infers that the unusual corrosion resistance properties of HEAs might be due to the local distortion/disordered chemical environment. So deposition of HEAs with their superior corrosion resistance onto the surface of the materials leads to the formation of corrosion-resistant layer or coating, and this has found wide applications in aviation industries. The chapter also describes thermal spray technology which is currently being used for the deposition of HEAs.

Chapter 5, which starts the part on characterization, talks about characterization and processing of PMMA/SiO_2 nanocomposite films and their applications. In this chapter, authors have synthesized polymethyl methacrylate (PMMA) using its monomer methyl methacrylate. The synthesized polymer was spun into a thin film using the Laurell Spin Coating System along with infused aerosil silica nanoparticles. The thin film was further tested for its thermal properties via thermogravimetric analysis, and mechanical properties were investigated using tensile testing. The infusion of the nanoparticles at varying weight ratios has shown improvement in both mechanical and thermal characterizations for the polymer.

In Chap. 6, an innovative technique, indentation technique was discussed for characterization of coatings. Instrumented indentation tests are most promising, reliable and easy non-destructive testing procedures in the material research, and these procedures are extended to characterize the coatings developed on the surface of the substrates. Indentation tests are conducted at different length scales, i.e. macro- to nano-levels. The indentation test data is used to determine different mechanical properties of the coatings. This chapter gives different numerical procedures or analytical models used to evaluate the elasto-plastic deformation behaviour of coatings by using indentation data.

Chapter 7, the commencing chapter of the last section of the book, i.e. Part IV, concentrates on FE-RSM modelling of wire drawing of brass-plated steel wire. It provides a brief description of the concept of wire drawing, which is a material deformation process in which the cross section of the wire or rod is reduced by pulling the wire or rod through a single or a series of converging dies. In this chapter, a three-dimensional elasto-plastic finite element (FE) model of wire drawing process is developed using ANSYS®. The brass-plated high carbon steel wire is used as the wire material, while the polycrystalline diamond is used as the die material. The von Mises yield criteria, associative flow rule and isotropic work hardening are implemented in the plasticity model. The FE model predicts the drawing stress on wire and die, in response to the selected wire drawing process parameters. The results of the FE model are used to feed the experimental matrix designed to develop the empiric models using the surface response method (RSM). Models are validated using test results and found to be consistent within the range of the parameters studied. The effects of the wire drawing parameters on drawing stress are also investigated and discussed.

The concluding chapter of the section and the book, Chap. 8, concentrates on *optimization,*, i.e. optimization of process parameters for AA6063 alloy friction surfacing on mild steel. The main aim of the present chapter is to achieve the optimal relationship between the friction surfacing process parameters and the process response that can be utilized for AA6063 aluminium material coating on the mild steel. To optimize the process parameters, factorial experimental design approach was implemented in which rotational speed of the consumable rod, axial load and substrate traverse speed parameters were predominantly influencing the friction surfacing process response. After the experimental result analysis, it was concluded that the sound coating was developed at (i) high rotational speed and with low axial load and traverse speed (ii) lower rotational speed and with higher axial load and traverse speed.

First and foremost, we would like to thank God. It was His blessings that this work could be completed to our satisfaction. You have given the power to believe in passion, hard work and pursue dreams. We could never have done this herculean task without the faith they have in you, the Almighty. We are thankful for this.

We thank our families for having the patience with us for taking yet another challenge which decreases the amount of time we could spend with them. They were our inspiration and motivation. We would like to thank our parents and grandparents for allowing us to follow our ambitions.

We would like to thank all the contributing authors as they are the pillars of this structure. We would also like to thank them to have belief in us. We would like to thank all of our colleagues and friends in different parts of the world for sharing ideas in shaping our thoughts. Our efforts will come to a level of satisfaction if the professionals concerned with all the fields related to coatings get benefitted.

We owe a huge thanks to all of our technical reviewers, Editorial Advisory Board Members, Book Development Editor and the team of **Springer Nature** for their availability for work on this huge project. All of their efforts helped to make this book complete, and we could not have done it without them.

Last, but definitely not least, we would like to thank all individuals who had taken time out and help us during the process of editing this book; without their support and encouragement, we would have probably given up the project.

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Part I
Processes

Chapter 1
Friction Stir Processing: A Novel Way to Produce the Surface Composite Coating

Shalok Bharti, Nilesh D. Ghetiya, and Kaushik M. Patel

Abstract Surface properties are important for a particular application such as marine, aerospace etc. In these applications, the required properties of the material depends only upon its surface properties. Therefore the enhancement in surface properties of the material is sufficient for such applications. Friction stir processing (FSP) provides a simple solution to enhance the surface properties of the material by producing a surface composite coating over the base material. Various properties like hardness, strength, corrosion, wear, microstructure, etc. can be enhanced by using FSP. An approach is made in this chapter to provide an understanding of composite materials and surface composite coatings. The information about FSP and how surface composite coating is prepared by FSP is discussed in detail. Previous work on FSP along with its effect on various properties and microstructure of the material has been presented in this chapter. Finally, the future scope and conclusion have been discussed in the end.

Keywords Friction stir processing · FSP · Coating · Composite · Surface modification · Material processing

1.1 Introduction

Friction stir processing (FSP) is the variant of Friction stir welding (FSW) which was developed in 1991 by "The welding institute (TWI)". FSW is used to join the similar or dissimilar material with the help of a rotating tool which consists of the pin and a shoulder. The friction between the rotating tool and surrounding material

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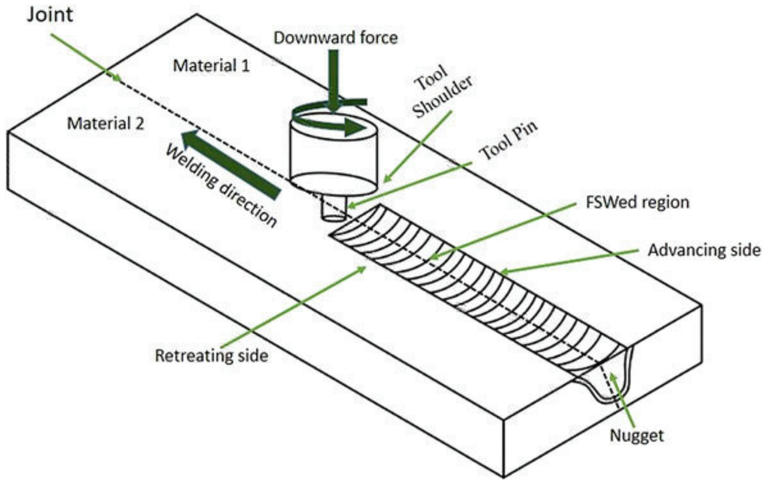


Fig. 1.1 Working of FSW

produces the friction which helps to convert the material into a solid-state phase. The stirring action of the tool helps in the movement of the semi-solid material from one side towards the other, creating welding between the two materials. This technique has been used in several applications like aerospace, automobiles, etc. where the joining of two materials with different properties is an essential part of the application. Recently it has begun to use in air or immersed medium to tackle the problem of microstructure softening [1, 2]. Figure 1.1 shows the working of FSW.

FSP works on a similar principle of FSW. Instead of joining the two materials, the rotating tool is passed over the material to improve the property of the material. Various properties like microhardness, wear, microstructure, etc. can be enhanced by this technique. FSP was first produced to achieve superplasticity into the material but with time, it has been used to provide enhanced material properties and surface composite coatings. Different process parameters of FSP helps the material to achieve enhanced properties. Figure 1.2 shows the working of FSP.

Composite materials are the materials in which the two or more materials are added or mixed to enhance the properties of the base material. In it, the reinforcement material helps to achieve the enhanced properties. There are various types of composites that can be developed depending upon the type of material used. In composite material, the whole base material is converted into the composite material which proves costlier than the surface composite coating. In surface composite coating, only the required surface of the base material with particular depth is converted into the composite material and below the surface remains unchanged. FSP is one of the best methods to achieve such a surface composite coating. The reinforcement particles are inserted into the base material and then the rotating tool helps to mix the reinforcement particles and surrounding materials with the help of heat which produces due to the friction.

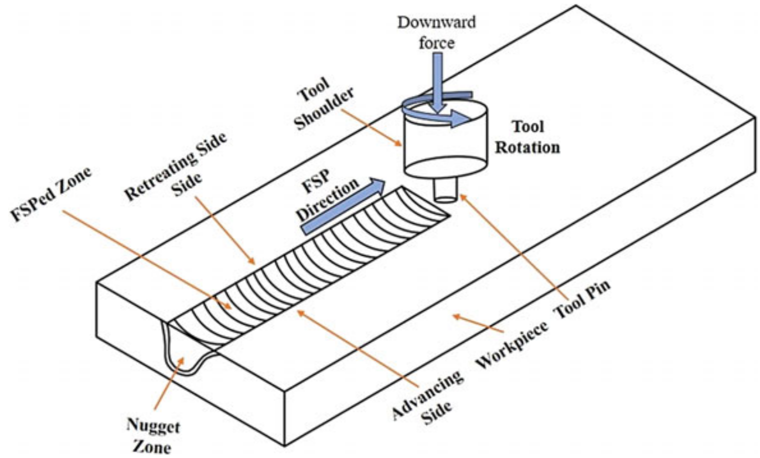


Fig. 1.2 Schematic of FSP

A large amount of literature is available discussing the surface composite coating by FSP and how it enhances the properties of the material. In this paper, the working principle of FSP and how it helps to produce surface composite coating is discussed. Previous work in this field is presented in the tabular form along with its effect on different material properties. Future trends and conclusionsare discussed in the end.

1.2 FSP Working Parameters

FSP works on the basic principle of Friction Stir Welding (FSW) which was developed "by "The Welding Institute (TWI)" in 1991 [3]. FSP consist of a rotating tool which involves an assembly of pin and shoulder. The workpiece is placed over the backing plate and clamped on the bed of the FSP machine. The rotating pin is provided with an axial force and descended into the workpiece so that the tool pin comes in contact with the workpiece and is further inserted till the shoulder comes in contact with the workpiece. Figure 1.3 shows the pin and shoulder in FSP tool used in the process.

After inserting the rotating tool into the workpiece, the tool is provided with a traverse speed which helps the tool to move in the transverse direction. This rotating and traverse action of the tool produces the heat due to the friction and helps the material to undergo intense plastic deformation and dynamic recrystallization [4]. Due to the heat produced during the process, the workpiece material converts to the semisolid state. Tool rotation helps in the movement of this semi-solid material from the advancing side of the workpiece toward the retreating side of the workpiece. This stirring action helps in the microstructure refinement and thus enhancing the material properties.

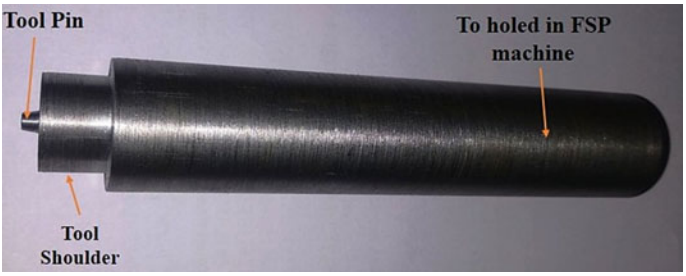


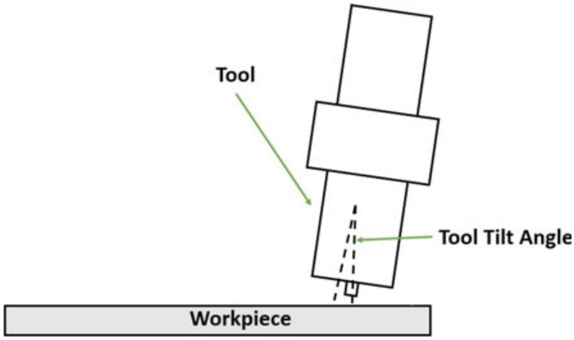
Fig. 1.3 Tool pin and tool shoulder in FSP tool

The tool rotating speed and the traverse speed plays an important role in FSP. These speed helps the process to maintain the amount of heat produced during the process. More tool rotating speed produces more heat due to friction and vice versa whereas, on the other hand, more traverse speed reduces the contact time between the tool and the shoulder and hence reduces the amount of heat. In order to produce the material with enhanced properties, the amount of heat should be optimum. If the amount of heat produced is less, then the microstructure deformation will not take place whereas if the heat production is more, then the microstructure softening will take place. Therefore optimum speeds should be chosen during the process.

Another important parameter that should be taken care of during the process includes tool tilt angle, tool dimensions, pin profile, and the number of passes. These parameters play an important role to enhance the material properties during FSP. Tool tilt angle is the angle by which the tool is tilted towards the workpiece. Tool tilt is necessary during the process because it is due to this angle that the movement of semisolid material is possible in the material. Mahallawy et al. [5] in their study of FSP to produce Al 1050/SiC surface composite suggested that the tool tilt angle should be between 2° and 4° otherwise cavity defects can be developed in the workpiece [6, 7]. Figure 1.4 shows the schematics of the tool tilt angle during FSP.

FSP tool consists of the pin and the shoulder. The dimensions of this pin and shoulder are important parameters to decide during the process. The height and

Fig. 1.4 Tool tilt angle



diameter of the tool pin require to be in accordance with the dimension of the material to be processed. In general, the pin height and pin diameter should be equal. Shoulder diameter decides the area of processing. Therefore it should be in accordance with the required area of the processing. Figure 1.5 shows the sample dimension for the tool dimension. It should be noted that the end of the tool should be in according to the chuck holder of the FSP machine.

Pin profile is the shape of the pin used for the process. Various pin profiles have been developed and used for the FSP. It was found that the pin profile helps in the easy movement of the material during the process. Some of the pin profile used for the process includes a cylindrical pin, threaded pin, square pin, triangular pin profiles, etc. Some of these pin profiles are shown in Fig. 1.6.

Various other parameters like plunge depth, axial force, clamping design, etc. play an important role during the process. To enhance the properties and microstructure

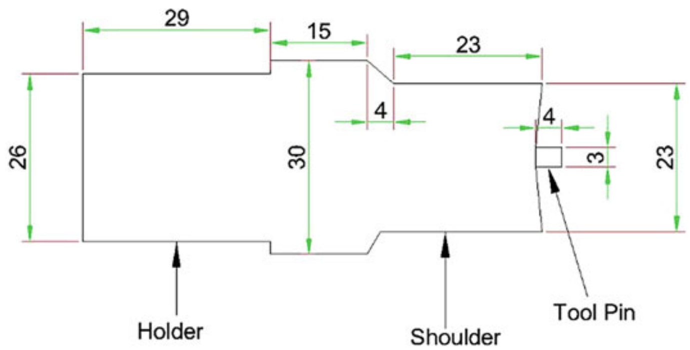


Fig. 1.5 Dimension of a tool being used in FSP

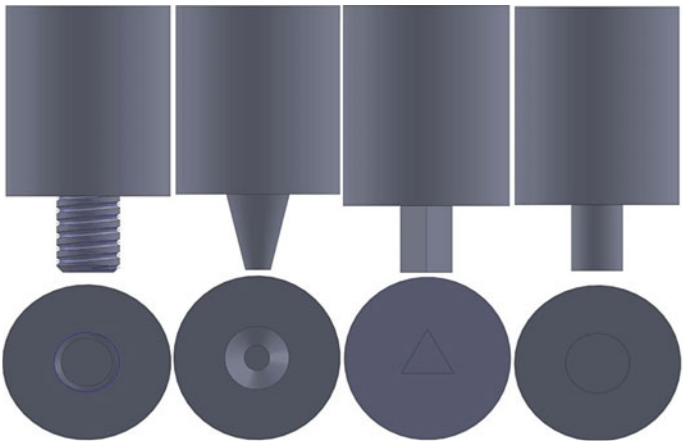


Fig. 1.6 Different pin profiles for FSP