

Interlaminar Contact Development During Thermoplastic Fusion Bonding

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Fabrication of layered thermoplastics and thermoplastic-matrix composites using processes such as tow placement, tape laying, and resistance welding is fundamentally based on the principle of fusion bonding, which involves applying heat and pressure to contacting thermoplastic surfaces. One of the important processing steps—*intimate contact development*—is considered in this paper. Interlaminar intimate contact development has a strong dependency on the thermoplastic surface geometry. Profilometric measurements of common thermoplastic prepreg tows, such as AS4/PEEK and IM7/PIXA, show that surface roughness features appear at several length scales and that the surfaces have fractal asperity structures. In this paper, principles of fractal geometry are used to describe prepreg surfaces. Based on this description, a microscale fluid flow model is developed to relate a degree of intimate contact to the process parameters (pressure, temperature, and time) and the fractal parameters of the surface. The model development and comparisons with experimental data are presented and discussed.

1. INTRODUCTION

Fusion bonding is the principal phenomenon that takes place during the manufacture of thermoplastic composites via processes such as thermoplastic tow placement, tape laying, filament winding, and resistance welding, to name a few. The process, shown schematically in *Fig. 1*, fundamentally consists of applying heat and pressure to two thermoplastic surfaces in contact. The applied heat causes the material to soften, while the simultaneous application of pressure causes the softened asperities to spread, resulting in a contact area development, called *intimate contact*, at the interface between the thermoplastic surfaces. The high temperatures at the interface lead to interdiffusion of polymer chains across the area in intimate contact, a process referred to as *healing*. The applied pressure and temperature further serve to consolidate the voids present within the tows, prior to cooling down and solidification of the material.

The main goal of fusion bonding is to produce a monolithic structure by intimate contact, molecular interdiffusion healing, and interlaminar void reduction. In particular, the coupled processes of intimate contact and healing contribute to interfacial bond

strength development, a principal parameter determining the quality of the composite products. Design of the processes and prediction of the interlaminar bond strength call for a reliable description of the intimate contact development and healing during the processing. Since the molecular interdiffusion can occur only when the materials at the interface are in contact with each other, intimate contact becomes a prerequisite for the development of fusion bonding. The focus of this paper is the modeling of intimate contact process, while studies of the healing process, a challenging problem in itself, can be found in the literature [for example, (1, 2)]. The intimate contact process is a function of manufacturing process parameters, namely, pressure, temperature, and time, and the geometry of the thermoplastic surface asperities. Of these, the geometric description of the thermoplastic surfaces is the critical and challenging step in the modeling.

A model of intimate contact by Dara and Loos (3) represented the thermoplastic surfaces as a wave of rectangles of different sizes. Lee and Springer (4) followed up on this model but simplified the geometry as a collection of rectangles of the same size. One limitation of these models is that the geometric parameters, i.e., the height, width and spacing of the rectangular elements, cannot be determined by direct surface measurements, and are obtained by fitting the model

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