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Finite element modeling of transmission laser microjoining process

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Abstract

Use of laser beam in high precision joining of two dissimilar materials has become a very useful technique. It has potential application in biomedical implants and their encapsulation process. In this research, a numerical method is developed using finite element technique to determine the optimum condition of jointing two dissimilar materials namely titanium and polyimide. Non-uniform discretization with large number of elements in the areas of high temperature gradients were used. The accuracy of the current numerical model was verified by comparing sample results with experimental data and good match was found. This gave us the confidence that the current method can be used for other combination of materials. It was observed that for a particular value of the laser power, good bonding between the dissimilar materials is a function of laser scanning speed. Too high speed will not produce any significant increase in temperature at the bimaterial interface to have a good chemical bonding. On the other hand, too slow speed will cause excessive increase in temperature resulting in burnout condition for polyimide. For the ranges of parameters investigated in the current study, it was observed that for a leaser heat flux of 4.0 W, good bonding occurs for a laser scanning speed between 600 and 2000 mm/min. It was also observed that increased scanning speed causes the temperature contour to stretch in the horizontal direction.

Keywords: Laser joining; Finite element; Laser parameters; Bioencapsulation

1. Introduction

Researchers focused on laser manufacturing process since early 1970s because of its many advantageous features over other conventional joining techniques and this process became useful for large-scale industrial production. Work has been done to estimate temperature distribution, keyhole as well as bond dimensions and residual stress in the metal-to-metal joining process [1–5]. With advancement of micro-electro mechanical systems (MEMS), this technique was considered as one of the most suitable processes because of its high precision and low distortion to the substrate materials. With the advent of biomedical implants and their encapsulation, the laser bonding technique has potential to become a unique joining process for its high precision and biocompatibility property, as no additional adhesive materials are required in this case. Our research group in collaboration with Fraunhofer USA has been studying the applicability of laser fabrication process in joining dissimilar and biocompatible materials [6–14].

Joining of dissimilar biocompatible materials such as titanium, polyimide and glass differs from metal-to-metal joining as studied in references [1–5] because of their differences in optical and thermal properties. In this case, laser energy is absorbed by nontransparent layer, converted into heat energy and transferred to the adjacent layer facing the gap resistance between layers. Transmission laser joining at micro scale has not been studied well yet. We studied the laser microjoining of dissimilar and biocompatible materials using both diode and fiber lasers and observed that the joining of glass to silicon and polymer to metal is very promising [13]. As part of the study, we developed an experimental setup (Figs. 1 and 2) that includes two laser parameters such as laser power and scanning velocity. The test data in Fig. 3 show the appropriate conditions to form a good bond between titanium and polyimide. It is clear from the diagram that a large number of samples are required to identify optimum process parameters. Hence, conducting such

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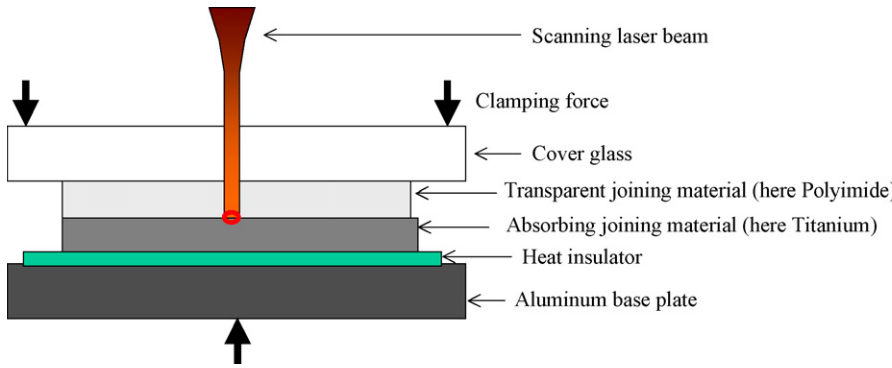

Fig. 1. Schematic diagram of transmission laser microjoining process.

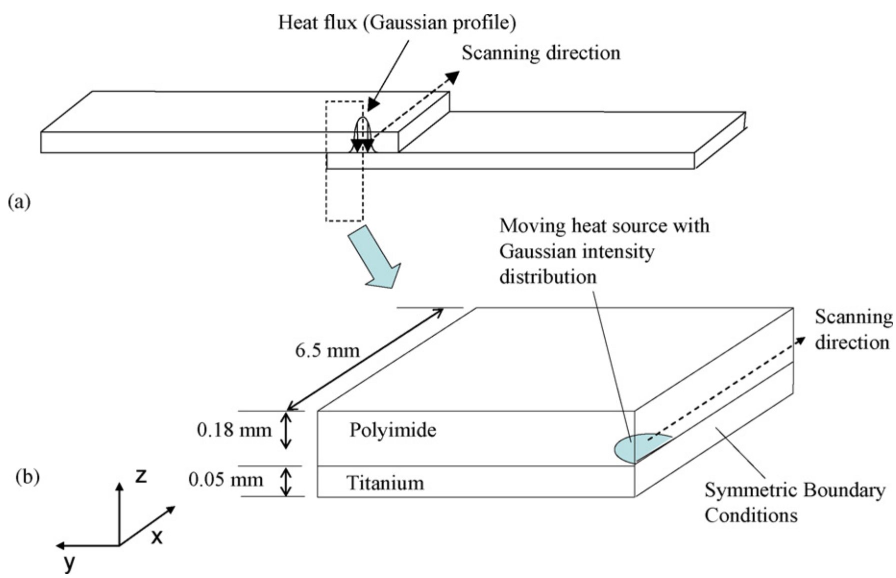

Fig. 2. (a) Schematic of the sample and (b) one-half model near the bond region with symmetric boundary conditions.

experiment is expensive and sometimes tedious and inefficient. On the other hand, numerical modeling of the laser processing to develop such process diagram is less expensive and saves a great deal of time. The most important feature of this method is that it gives the real picture of the complicated process including the effect of individual process parameter as well as the interaction of different parameters.

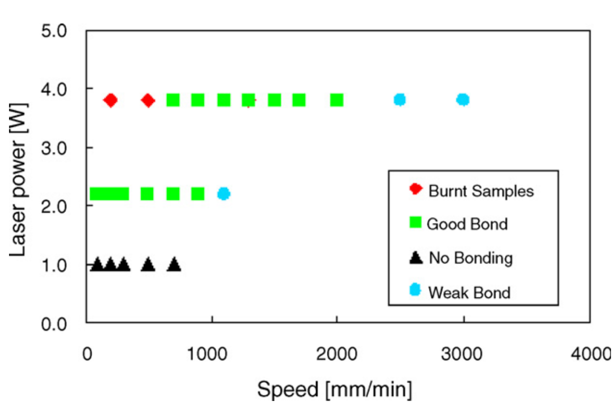

Fig. 3. Test data for polyimide to titanium bonding using fiber laser.

In this paper, the finite element analysis (FEA) technique has been employed to model the transmission laser microjoining technique. The laser energy is converted into heat and is absorbed by the opaque surface, which is transferred to the adjacent and surrounding layer through conduction and radiation. A good bond is observed if the temperature in the joining layers prevails within their melting point and burnout point. In this study, only three process conditions all with a power level of 4 W and scanning velocities of 100, 800 and 3000 mm/min are considered. For all the three conditions, analyzed a three-dimensional heat transfer model and transient heat analysis was performed to get temperature distribution with time and space. The bond characteristics in the three process conditions are compared with the test data shown in Fig. 3. In addition, the FEA predicted bond width is compared with the experimental measurements using a microscope.

2. Transmission laser joining

The ideal material combination to be joined using transmission laser process includes one absorbent and one transparent part. The laser energy penetrates the transparent part and is