Mechanics of Materials 40 (2008) 982–1000

Contents lists available at ScienceDirect

Mechanics of Materials

journal homepage: www.elsevier.com/locate/mechmat

Thermomechanical analyses of ultrasonic welding process using thermal and acoustic softening effects

A. Siddiq *, E. Ghassemieh

Mechanical Engineering Department, The University of Sheffield, Mappin Street, Sheffield, Yorkshire S1 3JD, UK

ARTICLE INFO

Article history:
Received 1 August 2007
Received in revised form 13 June 2008

Keywords:
Ultrasonic welding
Thermomechanical analysis
Friction laws
Ultrasonic softening

ABSTRACT

Ultrasonic welding process is a rapid manufacturing process used to weld thin layers of metal at low temperatures and low energy consumption. Experimental results have shown that ultrasonic welding is a combination of both surface (friction) and volume (plasticity) softening effects. In the presented work, a very first attempt has been made to simulate the ultrasonic welding of metals by taking into account both of these effects (surface and volume). A phenomenological material model has been proposed which incorporates these two effects (i.e. surface and volume). The thermal softening due to friction and ultrasonic (acoustic) softening has been included in the proposed material model. For surface effects a friction law with variable coefficient of friction dependent upon contact pressure, slip, temperature and number of cycles has been derived from experimental friction tests. Thermomechanical analyses of ultrasonic welding of aluminium alloy have been performed. The effects of ultrasonic welding process parameters, such as applied load, amplitude of ultrasonic vibration, and velocity of welding sonotrode on the friction work at the weld interface are being analyzed. The change in the friction work at the weld interface has been explained on the basis of softening (thermal and acoustic) of the specimen during the ultrasonic welding process. In the end, a comparison between experimental and simulated results has been presented showing a good agreement.

© 2008 Elsevier Ltd. All rights reserved.

1. Introduction

Ultrasonic welding is a process in which ultrasonic energy is used to create a solid-state bond between two pieces of metal. Ultrasonic welding is a versatile and powerful joining technique in the microelectronic packaging industry because of the low temperature, high yield rate and flexibility of the process (Harman, 1997). The main advantages of ultrasonic welding include, absence of liquid–solid transformations, low energy consumption, no atmosphere control required, works for dissimilar metals, low temperature allows embedding of electronics, such as sensors and actuators and most importantly, it is environmental friendly and very fast (Dushkes, 1973; Hu et al., 1991; Mayer and Schwizer, 2002; Sheaffer and Levine, 1991).

The mechanism of creation of an ultrasonic weld has been under study since many decades but still not fully understood (Tucker, 2002). A very simple definition of the creation of a weld was proposed by Tucker (2002), i.e. creation of the weld is a process in which ultrasonic interfacial motion between the two mating surfaces breaks and disperse the surface oxides, dirt and other contaminants leaving clean intimate surfaces which then create bonds. Joshi (1971) has performed studies on ultrasonic welding of aluminium, copper and gold wires. A series of tests were performed to quantify temperature rise to determine if there exists localized melting during the weld formation. It was found that interfacial temperature readings were less than 70 °C suggesting that localized melting does not occur during ultrasonic welding of wire bonds. It was also found that inter-diffusion at dissimilar bond

* Corresponding author. Tel.: +44 7726467348.
E-mail address: a.siddiq@shef.ac.uk (A. Siddiq).

0167-6636/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.mechmat.2008.06.004

interfaces do not occur. Transmission electron microscopy studies of ultrasonic wire bonding were performed by Krzanowski (1990). Transmission electron microscopy (TEM) was performed to examine ultrasonic bonding of aluminium wire to various metal substrates. There was no evidence found of inter-diffusion of atoms from substrate to the foil or vice versa. Both Joshi (1971) and Krzanowski (1990) found substantial amount of plastic flow around the hard members. Harman (1997) found that the plastic deformation is not only seen with in the microstructure of the weld zones but also at the interface of the mating materials. Transmission electron microscopy studies by James (1990) and Kazumasa et al. (2003) showed that vacancies or voids, debris or surface contaminants or oxides, and dislocations were frequently observed near the bonding interface. Harman and Albers (1977) performed studies on aluminium and gold wire bonding in microelectronics. Their experimental results showed that ultrasonic bonding takes place primarily by means of a deformation mechanism (ultrasonic softening) rather than heating or sliding mechanism. Schwizer et al. (1999) studied the ultrasonic ball bonding process. It was shown that stick–slip motion is necessary for high quality bonding. Prieb (1999) performed experimental studies on the ultrasonic joining of copper–copper, copper–aluminium, copper–silver and copper–steel metal pairs. It was found that severe plastic deformation of the metal plays an essential role during joining. It was also found that region of maximum deformation is located below the top surface at the foil/sonotrode interface. It was also found that largest microstructural changes occur near the upper surface at the foil/sonotrode interface. It was proposed that main mechanisms which lead to the formation of a metallic bond are removal of oxide coatings, metal plastification and even flow in the boundary region. No evidences were found of volume melting of the metals, melting of the metals along the contact interface, diffusion of the metals or alloy components into each other at the weld interface.

Ultrasonic welding of two different alloys of aluminium, i.e. AA 6061 and AA 3003 was performed by Kong et al. (2003) and Kong et al. (2004a,b). Kong et al. (2003) performed ultrasonic welding of aluminium alloy 6061. It was found that a thick oxide film (magnesium oxide) exists along the weld interface. This oxide film gets compacted due to the dynamic interfacial stresses, generated during ultrasonic vibration, causing the oxide layer to form brittle ceramic bonds at the weld interface. It was also shown that the density of metallurgical bond can be increased by a simple cleaning procedure. The cleaning process consisted of simple cleaning with the help of a degreaser (petroleum distillate) and wiped with a clean cotton cloth to remove oxides and other contaminants. Micro-hardness tests on welded and un-welded AA 6061 specimens were performed in Kong et al. (2004a,b). It was found that hardness near the weld interface is larger than the hardness away from the interface. This difference in hardness values depicted that both, surface effect (friction) at the weld interface and ultrasonic softening (acoustic softening) in the material, were present during the welding. Similar studies were performed on aluminium alloy 3003 using ultrasonic welding (Kong et al., 2004a,b). It was found that unlike AA 6061, AA 3003 does not require cleaning prior to the welding. Gunduz et al. (2005) performed studies on the ultrasonic welding of zinc and aluminium at elevated temperatures (513 K). It was found that at such high temperatures, weld interface exhibits structures indicative of enhanced inter-diffusion and local melting of aluminium and zinc solid solution.

Cheng and Li (2007) investigated the heat generation and temperature profile during ultrasonic metal welding using micro sensor arrays. The materials used for welding were copper alloy and nickel substrate. It was found that temperature ranges from 100 to 250 °C for various loading cases.

Daud et al. (2006, in press) performed studies (both experimental and simulation) on ultrasonic assisted tension and compression behaviour of aluminium alloy 1050. All simulations were done using implicit mechanical analysis without temperature effects. A phenomenological approach was presented to simulate the deformation behaviour of aluminium alloy 1050 by reducing the friction forces when ultrasonic vibration is present. The friction force was reduced by assigning a very small friction coefficient. It was concluded that the effect of ultrasonic vibration on bulk properties of metals cannot be explained in terms of stress superposition and surface effects. It was also proposed that a clear understanding can be developed by studying, how is the ultrasonic energy absorbed by aluminium microstructure. Doumanidis and Gao (2004) and Gao and Doumanidis (2002) performed the mechanical analysis of an ultrasonic spot welding process of a metal foil on a substrate. The mechanical analysis was based on the definition of frictional boundary conditions at the foil/substrate interface. The friction boundary condition was defined by using the experimentally measured strain on the substrate surface and adjacent to the ultrasonic probe. A good agreement of time dependent strain was found at the foil/substrate.

Although, a number of researchers have performed studies on ultrasonic metal working and have reported both surface and volume effects in ultrasonic processing of materials. But the mechanisms describing these effects are not fully explained in quantitative manner for the case of ultrasonic welding. Also, a very few attempts have been made to simulate the ultrasonic welding process (Doumanidis and Gao, 2004; Gao and Doumanidis, 2002). In most of the theoretical and simulated works, the effect of ultrasonic vibration is attributed in the friction coefficient rather than taking into account both surface and volume effects.

In the present paper, a material model based on cyclic plasticity theory has been proposed to take into account the volume effects while a kinematic friction model has been proposed to include the contribution of surface effects during the ultrasonic welding. The proposed material and friction model are discussed in detail in the following.

2. Deformation behaviour of aluminium alloy 6061

Aluminium alloy (AA) 6060/6061 is one of the most commonly used aluminium alloy due to its versatile

Download English Version:

https://daneshyari.com/en/article/797806

Download Persian Version:

https://daneshyari.com/article/797806

Daneshyari.com