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A welding machine for thermoplastic polyimide (TPI) films: Novel apparatus and experimental investigations

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ABSTRACT

The utilization of thermoplastic polyimide (TPI) films for aerospace structures has attracted considerable attention in recent decades due to excellent thermal stability, high glass transition temperature and good mechanical properties. As engineering materials, TPI films with limited product width require suitable welding with respect to insolubility and infusibility resulting from planar structure and wholly aromatic structures. This paper focuses on the development of a novel welding machine and investigation on ultimate strength of original and welded TPI films. The resistance welding machine is proposed with specific functions for overcoming the difficulties in welding TPI films. A series of experiments in combination of temperature and pressure are carried out to assess the quality of welded TPI films. Additional experiments on welded specimens from three existing welding machines are performed to compare and justify performance of resistance welding machine.

The ultimate strength values of welded specimens are reasonable with a maximum reduction of only 2.73% in comparison with that of original specimens. It is revealed from experimental observations that one-parameter analysis (temperature or pressure) cannot draw suitable conclusions but that coupled two-parameter analysis could obtain suitable temperature range (290–295 °C) and pressure range (0–100 N). The confidence interval with the confidence coefficient of 0.95 is 71.2–72.8 MPa for the ultimate strength. The comparisons between five types demonstrate the feasibility of using this resistance welding machine to weld TPI films.

1. Introduction

The use of thermoplastic polyimides for aerospace, mechanical and electrical industries has attracted considerable attention in recent decades due to excellent thermal stability, high glass transition temperature and melting temperature, satisfactory mechanical and electrical properties [1,2]. Among these applications, aerospace structures under extreme space environmental conditions require superior physical, chemical and mechanical properties [3]. In general, thermoplastic polyimides that offer excellent resistance to space environmental factors, such as high-energy irradiance, UV radiant and temperature cycles, are commonly produced in the form of films for ease of processing, handling and storing [4]. Recent projects with TPI films are Interplanetary Kite-craft Accelerated by Radiation Of the Sun (IKAROS) [5] and Jupiter Magnetospheric Orbiter [6].

As engineering materials, physical and mechanical properties under typical and extreme conditions are indispensable for analyzing structural behavior to assess safety and serviceability. For physical properties, Kimoto et al. developed space-qualified coated polyimide films to enhance space environmental tolerance [3]. Yokota et al. proposed a novel asymmetric aromatic polyimide with good space environmental stability and successfully used it as solar sail membrane [7]. Huo et al. confirmed that a new thermoplastic polyimide had a very small amount of bound with dielectric and dynamic mechanical relaxation tests [8]. Generally, TPI films in use for structural element need more accurate mechanical properties than other functional applications. For this reason, Gofman et al. focused on effects of degree of crystallinity on mechanical properties and demonstrated that possible board temperature range could be achieved by regulating degree of structural ordering [9]. Saeed et al. investigated mechanical properties of TPI film in terms of imidization degree and suggested that elastic modulus and tensile strength increased with imidization degree while breaking elongation decreased after certain imidization temperature [4]. Nicholson et al. estimated the relation between molecular weight and elastic/viscoelastic properties of glassy thermoplastic polyimides. It is concluded that low molecular weight materials were less affected by physical ageing [10]. Nazarychev et al. correlated local mobility of heterocyclic polyimides and mechanical properties, finding that mechanical properties

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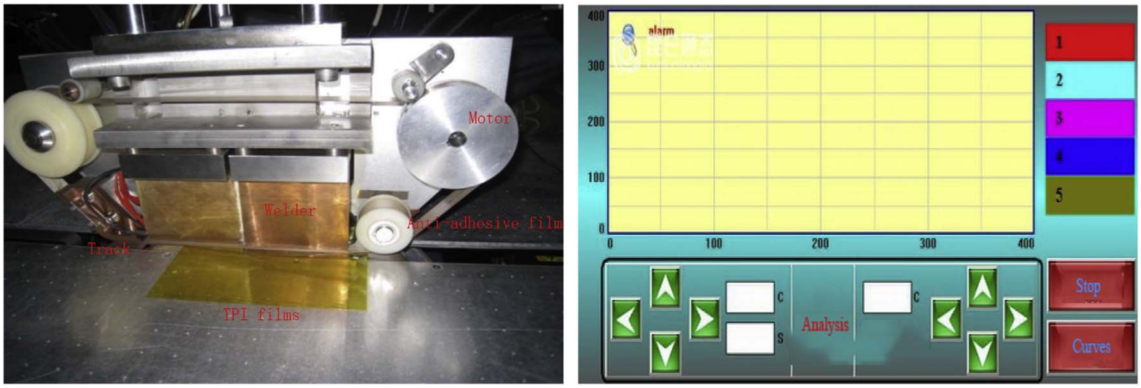

(a) (b)

Fig. 1. Resistance welding machine: (a) Photo, (b) Control interface.

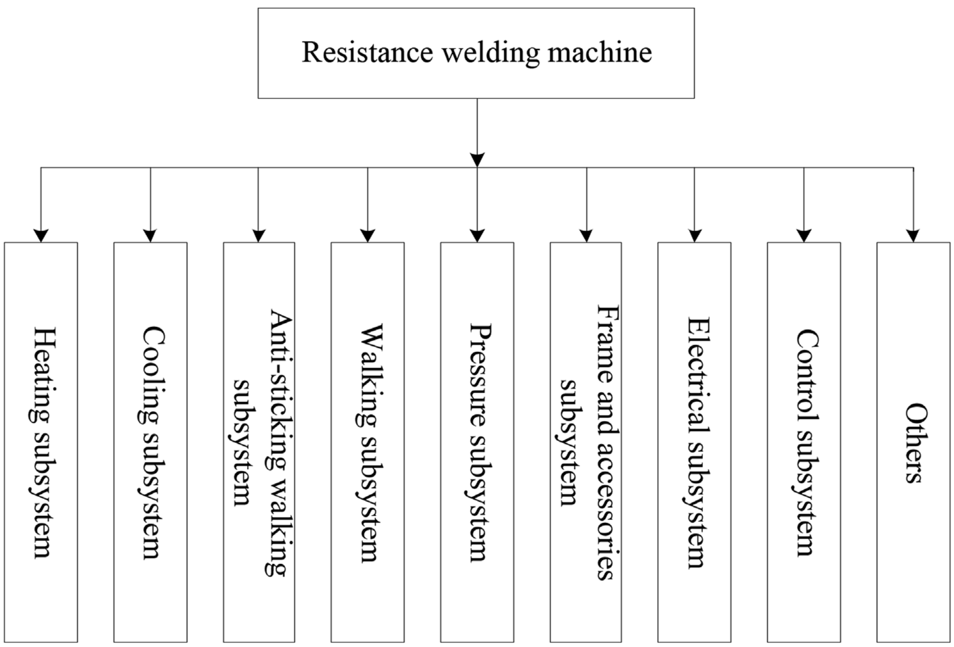

Fig. 2. Configuration of the resistance welding machine.

Table 1
Technical parameters of the resistance welding process.

Parameters	Range	Accuracy
Maximum welding length	6.5 m	0.5 mm
Welding temperature	100–340 °C	1 °C
Welding rate	1–10 mm/s	-

were directly connected to local segmental mobility above glass transition temperature [11]. Furthermore, Zhang et al. proposed a three-element Maxwell viscoelastic model for predicting stress-strain curves of TPI films under strain rate and temperature conditions [12].

On the whole, these studies only focused on mechanical properties of original TPI films but not on welded films. However, the use of TPI films to fabricate structures needs welding due to limited product width [2]. It is revealed that welding TPI film was difficult with respect to insolubility and infusibility due to planar structure and wholly aromatic structures [13]. Moreover, high pressure in welding could result in damage to bounded structure, entrapment of volatile products, etc. [14]. For these reasons, development of suitable welding machine and investigation on mechanical properties of welded TPI films are crucial for appropriate utilization of TPI films. Typical methods for joining plastics and polymers include thermal, ultrasonic and resistance methods [15]. Thermal welding is based on heat conduction to welding surfaces. The main disadvantage is that laser radiation absorbed by pigments could influence thermoplastics color [16]. Ultrasonic welding joins polymers through the heat generated from high-frequency mechanical motion while it needs better surface preparation than vibration welding [17]. Resistance welding has excellent performance and cost-effective over other joining techniques but the process is slow [18]. Therefore, existing techniques and equipment could not be directly utilized to weld TPI films. The addition of specific functions is necessary in relation to properties of TPI films, such as glass transition temperature, low thermal coefficient and poor adhesive properties [19]. However, after a careful survey of the literature, it appears that this area has not been well-addressed.

This paper focuses on developing a novel welding machine and investigating effects of temperature and pressure on ultimate strength of TPI films. The composition of this paper is organized as follows. A newly-developed resistance machine with specific functions is presented in Section 2. A series of experiments in combination of temperature and pressure are carried out and additional experiments on welded specimens from three existing welding machines are performed