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The influence of adhesive viscosity and elastic modulus on laser spot weld bonding process

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ABSTRACT

Laser spot weld bonding (LSWB) is a novel joining technology, which combines laser spot welding with a layer of structural adhesive in a single joint. The purpose of this paper is to investigate the effect of the adhesive properties on the joining process, the peel and the shear strength of the LSWB joints. The present work demonstrates that the adhesive viscosity has great influence on the vaporized adhesive gas exhaust process, and the low viscosity is good for the exhaust process. The mechanical test result shows that the tension–shear load of LSWB joint isn't always higher than that of the adhesive bonded joint, and LSWB joint with high elastic modulus of adhesive may get the same tension–shear load as the adhesive bonded joint gets. The reaction zone produced by the carbon diffusion between the adhesive and the metal sheet will influence the mechanism of LSWB joint.

1. Introduction

Weld bonding is first developed and used by USSR on planes of the type AN-24 [1]. This technology has the advantages of resistance spot welding and adhesive bonding combined [2]. At present, due to the excellent mechanical properties of weld-bonded joints, the weld bonding process has been widely used in automobile transmissions, railway carriages and aircraft [3–5].

A lot of researchers have investigated the influence of adhesive properties on resistance weld bonding (RWB) process, especially the viscosity and the elastic modulus of adhesive. As the technique used in the weld bonding process is the “weld-through” method, the adhesive is applied to the parts first, spot welded and subsequently cured [6], the structure adhesive must have good wetting and flow characteristics in order to get a fine joint [5]. During the research on the influence of adhesive elastic modulus, some questions and contradiction are revealed. Darwish et al. [7–9] carried out a 2D finite element model by means of *Calsef* FE program to investigate the stress distribution in the RSW joints. The investigation showed that the stress concentration at the periphery of spot-welded joint was decreased by the application of adhesive, and the principal stresses concentrated at the far ends of weld-bonded joints increased with the rising in the elastic modulus of adhesives. And some researchers have proved it [10]. Chang et al. utilized finite elements to analyze the thickness of the adhesives on the stress distribution in weld-bonded joints, and they pointed out that the utilization of an adhesive layer with a small thickness will smooth the stress concentration in weld bonded joints and improve their overall fatigue strength performance [2,11]. But GonÇalves et al. [12] studied the behavior of weld-bonded joints using different commercial adhesives under tension–shear test. The results demonstrate that the weld-bonded test specimens produced by using different adhesives show almost no differences from the ultimate load, which means that the adhesive elastic modulus doesn't influence the tension–shear process.

As entrenched as resistance welding is in the weld bonding process [10–15], Laser spot welding (LSW) has been seeing increased attempts. LSW, as an innovative technique, has the potential to substitute the conventional resistance spot welding method, since it possesses many advantages, for instance, being a none-contact single side method [16]. The Edison Welding Institute studied the laser spot weld bonding (LSWB) process for aircraft [17]. LSWB is a new joining process that combines laser spot welding with a layer of structural adhesive in a single joint. In the LSWB process, the laser beam interacts with the adhesive layer directly, causing the process unsteady. And this interaction was confirmed in Messler [18] and Liu's studies [19]. In our earlier work [20], a special pulsed laser, which consists of a pre-gasify phase and a welding phase, was employed to weaken the interaction between laser beam and the adhesive. And the pre-gasify

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phase of the special pulsed laser plays the same role as the initial loading phase does in resistance spot weld bonding (RSWB), which is to squeeze the adhesive layer out of the welding zone. But this effect maybe depends on the viscosity of adhesive.

The main objective of this study is to investigate the influence of adhesive viscosity and the elastic modulus on LSWB, two different adhesives were used in the experiment. The joining process and the mechanical properties with different adhesives were compared and analyzed.

2. Experiments

The sheet material employed in the experiment was St33 mild steel. And the chemical composition is shown in Table 1.

The welding equipment used in the experiment was a ROFIN-3000W CO_2 laser welding machine. The configuration and dimensions of the welding specimen used throughout the work are shown in Fig. 1. The specimens were prepared by abrading with 150-grid emery paper, degreasing with acetone, drying and storing in a desiccator before weld bonding.

Table 1
Chemical composition of St33 (wt%).

Material	C	Mn	Si	S	P
St33	0.06–0.12	0.25–0.5	0.30	0.05	0.045

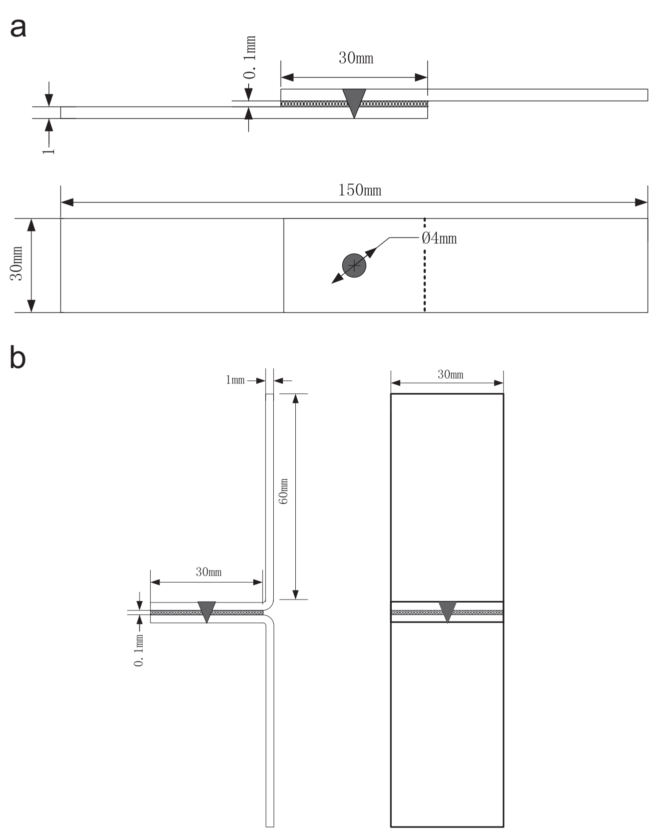

Fig. 1. Geometry and dimension (mm) of the test specimens. (a) Tensile-shear test. (b) Peel test.

Two different structural epoxy resin adhesives were employed in the experiment, shown in Table 2. The adhesive with a thickness of 0.1 mm was coated on the overlap area of the sheets. And the thickness of adhesive layer was controlled by a caliper. Then the spot-welded joints were made by laser beam. After the welding was completed, the weld-bonded specimens were cured under a fixed pressure by clamps in order to insure the well contact between adhesive and metal sheet during the curing process. In the present work, the pulsed laser is consisted of two periods with different laser power and pulse duration, as Fig. 2 shows. The first pulse is the pre-gasify pulse, and the second one is welding pulse.

The polished specimens were etched with a 4 percent Nital reagent and examined by scanning electron microscope (SEM). Two commonly applied methods of destructive testing were used, tension–shear testing and peel testing. The former indicates the maximum shear load that the joint can withstand before joint failure, while the latter is used for observing the shape and size of the torn-out nugget. Both tests were carried out on an INSTRON MODEL1186 testing machine using different tensile rate (3 mm/s in tensile-shear testing, 5 mm/s in peel testing). For comparison, those of adhesive bonded joints, laser spot-welded joints and LSWB joints under the same parameters were assessed. And the destructive test results of the LSWB joints using different adhesives were compared to analyze the influence of adhesive's properties.

3. Results and discussion

3.1. Joining process

To show the influence of adhesive viscosity on LSWB process, two different adhesives with different viscosity were used at the

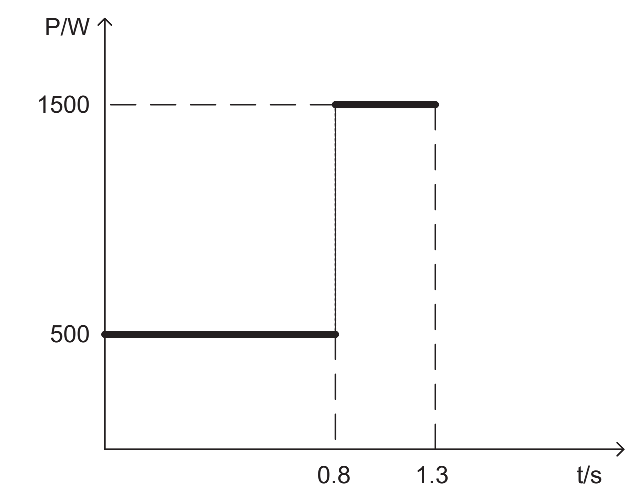

Fig. 2. The pulse waveform of pulse laser.

Table 2
Type and main characteristics of the adhesives applied in the investigation.

Adhesive	Type	Viscosity (Pa s) (40 mm parallel plate, shear rate 30 1/s)	Curing mechanism	Curing time	Elastic modulus (MPa)
A	Two component epoxy	12	Room temperature cure	48 h	1500
B	One component epoxy	520	Heat cure	3–4 h (at 180 °C)	2000