Materials Science & Engineering A 567 (2013) 95–100

Contents lists available at SciVerse ScienceDirect

Materials Science & Engineering A

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

Determination of the constitutive behaviour of AA6022-T4 aluminium alloy spot welds at large strains

Jidong Kang [a,*], Joseph R. McDermid [b,1], Moise Bruhis [b,2]

[a] CanmetMATERIALS, 183 Longwood Road South, Hamilton, ON, Canada L8P 0A5
[b] Department of Mechanical Engineering, McMaster University, 1280 Main Street West, Hamilton, ON, Canada L8S 4L7

ARTICLE INFO

Article history:
Received 20 April 2012
Received in revised form
3 July 2012
Accepted 4 July 2012
Available online 21 July 2012

Keywords:
Constitutive behaviour
Shear test
Spot welding
Aluminium alloys
Mechanical properties

ABSTRACT

There is increasing demand within the automotive industry to utilize aluminium alloy sheets and their spot welds to facilitate vehicle weight reduction and increase fuel economy. While traditional uniaxial tensile testing only determines mechanical properties to small strains, direct measurement of the constitutive behaviour of aluminium alloy spot welds to large strains remains a challenge. For the first time, the present work employed digital image correlation coupled with shear testing to directly measure the constitutive behaviour of an AA6022-T4 spot weld to large strains. The results show that the spot welding process not only decreases the yield strength but also lowers the work hardening rate of the nugget versus the base material. The paint bake cycle partially recovers the yield and shear strength of the nugget.

1. Introduction

There is increasing demand from the automotive industry to utilize aluminium alloy sheets and their spot welds for mass reduction and increased fuel economy [1]. The performance of aluminum alloy spot welds is critical to safety and structural life prediction. Over the years, tension shear, cross-tension and peel tests have been used to assess the mechanical properties of resistance spot welds [2,3]. However, only the maximum load tended to be reported for these tests [3]. This was due to two reasons: first, only a target nugget size for a given welding schedule is ensured while the real size remains unknown; second, the actual stress state of the nugget is complex and depends on the base materials, nugget size, loading condition and failure mode [4,5].

Appreciating the microstructural inhomogeneity of a welded joint, some researchers have employed uniaxial tensile testing coupled with full-field, non-contact strain mapping based on digital image correlation (DIC) to extract the constitutive behaviour of each region of the welded joint [6,7]. This concept has been extended to measuring the constitutive behaviour of spot welds using miniature tensile samples and tension shear samples [8,9]. However, the constitutive behaviour which can be determined from uniaxial tensile tests is limited by the instability of the weakest region of the welded joint or to small strains for the other regions. Direct measurement of the constitutive behaviour of aluminium alloy spot welds to large strains remains a challenge.

Shear tests avoid the instability that is often observed in uniaxial tensile tests and offers the advantage of being able to measure welded joint constitutive behaviour to large strains. Over several decades, a number of sheet material shear test sample geometries have been developed, ultimately resulting in the publication of the ASTM B831-93-05 standard [10] for the shear testing of aluminium sheet materials. However, this standard provides guidelines only for the measurement of shear strength. A modified shear test coupled with digital image correlation was recently developed by Kang et al. [11] and has been used successfully to measure the constitutive behaviour of aluminium sheet materials to large strains.

In this contribution, the newly developed shear test of Kang et al. [11] was adapted to directly measure the constitutive behaviour to large strains of aluminium alloy AA6022-T4 resistance spot welds destined for automotive applications. Often, these spot welds undergo a paint bake cycle during assembly. Thus, the effect of the paint bake cycle on the mechanical properties of AA6022-T4 spot welds was also quantified

2. Experimental

The material used in the present study was 2 mm thick AA6022-T4 sheets. The nominal alloy chemical composition is given in Table 1.

General Motors' proprietary resistance spot welding process [12,13] for aluminum alloy sheet was used to weld two pieces of

* Corresponding author. Tel.: +1 905 645 0820; fax: +1 905 645 0831.
E-mail addresses: jkang@nrcan.gc.ca (J. Kang), mcdermid@mcmaster.ca (J.R. McDermid), bruhis@mcmaster.ca (M. Bruhis).
[1] Tel.: +1 905 525 9140x27476; fax: +1 905 572 7944.
[2] Tel.: +1 905 525 9140x27869; fax: +1 905 5727944.

0921-5093/$ - see front matter © 2012 Crown Copyright and Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.msea.2012.07.014

Table 1
Nominal chemical composition of AA6022-T4 (wt%).

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others	Al
0.7–1.5	0.30	0.25	0.35	0.25–0.75	0.10	0.20	0.15	0.05 other each; 0.15 other total	Balance

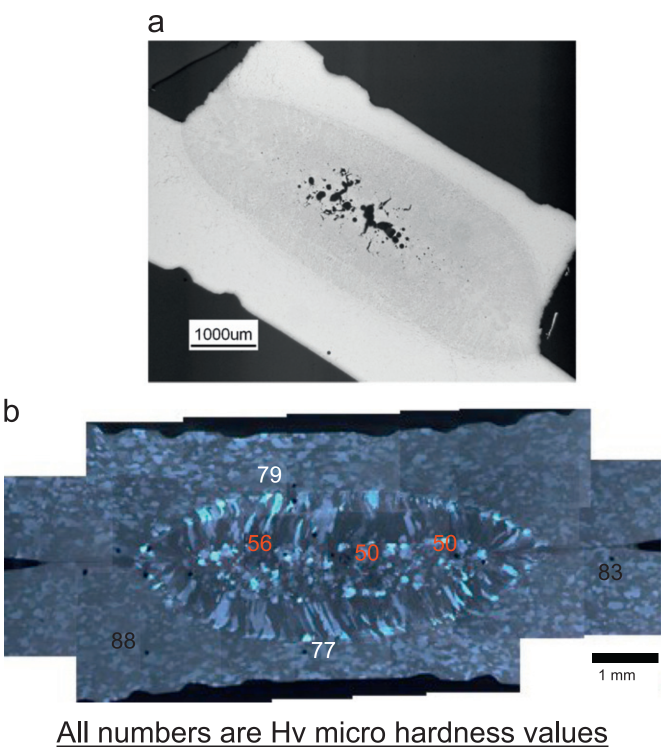

Fig. 1. Microstructure of an AA6022-T4 spot weld (a) macro-etched structure; (b) finer scale grain structure and Vicker's hardness of spot weld zones.

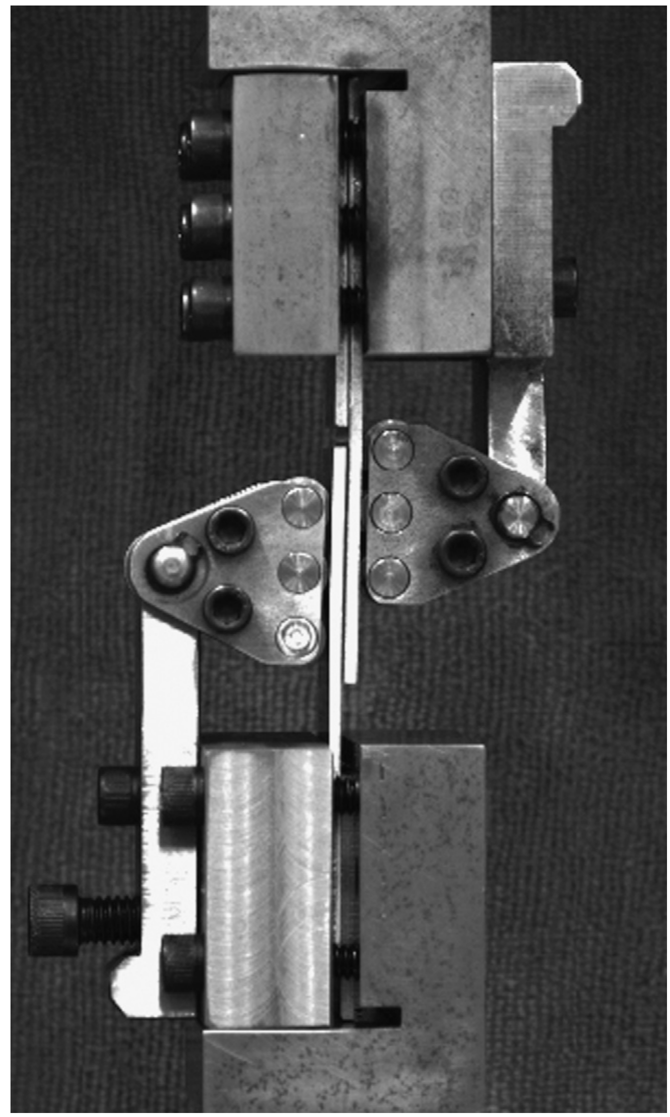

Fig. 2. Tension shear test with roll-guides.

2 mm thick AA6022-T4. Each piece was 150 mm long and 38 mm wide. The spot welding schedule was 4450 N applied force, 3 ms upslope from 12 kA to 31 kA welding current and 133 ms welding time at the 31 kA program current. The target nugget size was 6.5 mm.

In practice, aluminium spot welds usually undergo two high temperature paint shop bakes. These paint shop bakes have been simulated as a two-step heat treatment using a high temperature furnace, i.e., (1) electrophoretic priming operation (ELPO) bake at 171 °C for 30 min followed by air cooling to ambient temperature; (2) primer sealer bake at 171 °C for 20 min followed by air cooling to ambient temperature. In both cases the heat-up ramp time was less than 10 min. For the sake of simplicity, samples subjected to the paint shop bakes are denoted as "baked samples" whereas those not subjected to the paint shop bakes are denoted as "as-welded samples".

In order to determine the nugget depth for shear and tensile sample preparation, selected as-welded spot welds were cross-sectioned along the weld centreline for metallography. First, the welds were macro-etched using Keller's solution to reveal the spot weld macrostructure. Typical defects such as voids and micro-cracks were found in the central part of the nugget (Fig. 1a). Further, some of cross-sectioned samples were mounted and polished to 0.05 μm colloidal silica using standard metallographic techniques. Anodizing was conducted using Keller's solution and a DC current of 20 A. The spot weld microstructure was observed using a Nikon inverse optical microscope at a magnification of 200 × (Fig. 1b). From Fig. 1b, it can be seen that the maximum penetration of the nugget was approximately 0.75 mm from each side of the sheet with a relatively uniform grain structure and hardness profile.

Tension shear tests were carried out to obtain the shear strength of the as-welded AA6022-T4 spot welds. A roll-guide was attached to both sides of the sample (Fig. 2) to ensure loading line alignment. After the tests, the fractured samples were collected to measure the area of the fracture surfaces using a Nikon stereoscope and NIS elements software.

Some of the as-welded spot welds were separated and sectioned to a thickness of 0.6 mm, as illustrated in Fig. 3a, to make tensile