Journal of Manufacturing Processes 30 (2017) 63–74

Contents lists available at ScienceDirect

Journal of Manufacturing Processes

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

Technical Paper

# Effect of welding parameters on tensile strength of ultrasonic spot welded joints of aluminum to steel – By experimentation and artificial neural network

Dewang Zhao [a,f], Daxin Ren [b,d,*], Kunmin Zhao [b,c,*], Sun Pan [e], Xinglin Guo [a]

[a] Department of Engineering Mechanics, State Key Laboratory of Structural Analysis for Industrial Equipment, Dalian University of Technology, Dalian 116024, China
[b] School of Automotive Engineering, Dalian University of Technology, Dalian 116024, China
[c] Institute of Industrial and Equipment Technology, Hefei University of Technology, Hefei 230601, China
[d] Key Laboratory of Liaoning Advanced Welding and Joining Technology, Dalian University of Technology, Dalian 116024, China
[e] Shanghai Shipyard CO., Ltd., Shanghai 200000, China
[f] School of Architecture and Civil Engineering, Northeast Petroleum University,99 Fazhan Street, Daqing, China

ARTICLE INFO

*Article history:*
Received 2 June 2017
Received in revised form 4 August 2017
Accepted 19 August 2017

*Key words:*
Ultrasonic welding
Aluminum alloys
Steel
Welding parameter
Artificial neural network

ABSTRACT

Aluminum and steel are widely used in automotive and aerospace industries. As a new type of solid-phase welding, ultrasonic spot welding is an effective way to achieve joints of high strength. In this paper, ultrasonic welding was carried out on aluminum-steel dissimilar alloys to investigate the influences of welding parameters on joint strength. Designed and conducted a 3-factor, 3-level comprehensive test. The analyses of test results show that there are 3 kinds of fractures on the welding joint with different welding parameters. The highest strength can reach 3910 N. Clamping force and vibration amplitude not significantly impact the tensile strength. Vibration time significantly impact the tensile strength although its significance level is close to the threshold. The interaction between welding parameters all can significantly impact the tensile strength. The artificial neural network optimized by Genetic Algorithm was used to establish an analytical model. The supplemental experiment and residual analysis were conducted to verify the accuracy of the analytical model. The analytical model show that with the increase of clamping force, the changes of optimal and minimum strength are limited, but the range of welding parameters to obtain a higher strength change significantly; the optimal welding parameters from lower vibration amplitude and higher vibration time shifts towards to higher vibration amplitude and shorter vibration time gradually; for 0.3 Mpa clamping force, the influences of vibration amplitude and vibration time on tensile strength are not significant.



## 1. Introduction

Ultrasonic welding is a type of solid-phase welding. Under static pressure, it converts the elastic vibration energy into the frictional work, deformation energy and limited temperature rise between work-piece interfaces, to instantly activate the atoms in the welding area of the work-piece and to enable mutual penetration of the molecules at the interface of the two phases, ultimately achieving the solid connection of the weldment [1]. At present, high strength connection of the materials including aluminum, magnesium, titanium and copper alloys have been realized.

Since the discovery of UW in the 1950s, it has been widely used in many applications, including tube sealing and wire joining. Recently, HyungSeop Shin [2] focused on a parametric study in similar ultrasonic spot welding of A5052-H32 alloy sheets. Research indicates that longer welding time produced over welding which gave short but intensified weld interface waviness, resulting to a shorter fracture path. Farid Haddadi [3] investigated the effect of zinc coating on the mechanical properties and interface reaction of aluminium to steel ultrasonic spot joints. Research show that the maximum strength of aluminium to DC04 and DX56-Z steel ultrasonic spot joints were only slightly lower (5–10%) than the

* Corresponding authors at: School of Automotive Engineering, Dalian University of Technology, 2 Ling Gong Road, Dalian, 116024, China.
*E-mail addresses:* dewangzhao@qq.com (D. Zhao), rendx@dlut.edu.cn (D. Ren), kmzhao@dlut.edu.cn (K. Zhao).

http://dx.doi.org/10.1016/j.jmapro.2017.08.009
1526-6125/

performance of aluminium–aluminium joints. V.K. Patel [4] conduct ultrasonic spot welding on AZ31B-H24 Mg alloy sheet by varying a key parameter of welding energy, aiming to identify the changes in the microstructure, crystallographic texture, and lap shear tensile strength. They also conduct ultrasonic spot welding on aluminum-to-galvanized high-strength low-alloy (HSLA) steel [5], SiCp/2009Al composite sheets [6], for the same research purpose. A. Panteli [7] investigated the effect of high strain rate deformation on intermetallic reaction during ultrasonic welding aluminium to magnesium. M. Shakil [8] performed ultrasonic spot welding of 3003 Aluminum with 304 Stainless steel alloy, to investigated the effect of ultrasonic welding parameters on microstructure and mechanical properties. Zenglei Ni [9] focused on the microstructure and mechanical performances of ultrasonic spot welded Al/Cu joints with Al 2219 alloy particle interlayer. The results show that, with increasing the welding energy, the lap shear tensile strength had an increasing trend and the hardness of aluminum metals decreased. The maximum tensile strength reached about 83 MPa at 1500 J welding energy, and the failure location was in the copper metal.

According to the previous literatures can be seen that, the mechanism of ultrasonic welding of similar and dissimilar metals have been explored from the perspectives of microstructure analysis, mechanical property analysis, temperature field distribution, and stress distribution [10,11,12]. Most research in the area of USW have worked on the microstructure and the tensile properties of the USWed joints. But less research worked on the influence of welding parameters on mechanical properties [13]. The mechanical properties are critical to welding applications. The synergistic effects of different parameters of ultrasonic welding such as clamping force, time, and amplitude impact the welded quality including the strength, fatigue life and dynamic response [14]. Annoni [15] employed three factors and three levels to comprehensively test the similar aluminum alloy AA 6022-T4 and adopted analysis of variance to investigate the influences of the welding parameters and their interactions on the mechanical property. Research indicates that the vibration amplitude shows the maximum influence on the tensile–shear strength of welded joints but also the effect of the vibration time and clamping force are generally significant, even if their magnitude is lower. All possible interactions between parameters seem to play a relevant role on the tensile–shear strength: in particular, the interaction between vibration amplitude and time is the strongest one in the studied ranges. In previous work, Zhao Dewang [16] employed three factors and three levels to comprehensively test the dissimilar magnesium alloy AZ31 and titanium alloy Ti6Al4V, adopted the analysis of variance and artificial neural network to investigate the influences of the welding parameters on the mechanical property, and get some different conclusions. Light metal and alloys have been increasingly used in automotive and aerospace industries to reduce weight, resulting in a greater need to join dissimilar materials. At present, aluminum and steel are widely used in automotive and aerospace industries. So in this study, AL 6061 aluminum alloy and A36 steel alloy were selected for ultrasonic welding. The influences of welding parameters on joint strength were studied through experimentation and artificial neural network.

## 2. Experimentation

### 2.1. Test setup

In this study, 1.5 mm thick A36 steel alloy (C-0.26, Fe-98.2, Cu-0.2, Mn-1.03, P-0.04, S-0.28 (wt.%)) sheet and 1.0 mm thick Al 6061-T6 aluminum alloy (Si-0.4, Fe-0.7, Cu-0.2, Mn-0.15, Mg-1.1, Al-97.45 (wt.%)) sheet are selected. The specimens are 100 mm long and 25 mm wide. The welding is conducted at a fixed power of 2500 W, a frequency of 20 kHz, and head size of 10*10 mm$^2$. In order to obtain the influences of various welding parameters on the joint strength, tensile shear tests are conducted to measure the failure load of the welded joints at a tensile speed of 1.0 mm/min. The schematic diagram of the welding setup and the appropriate weldment for tensile-shear test are shown in Fig. 1.

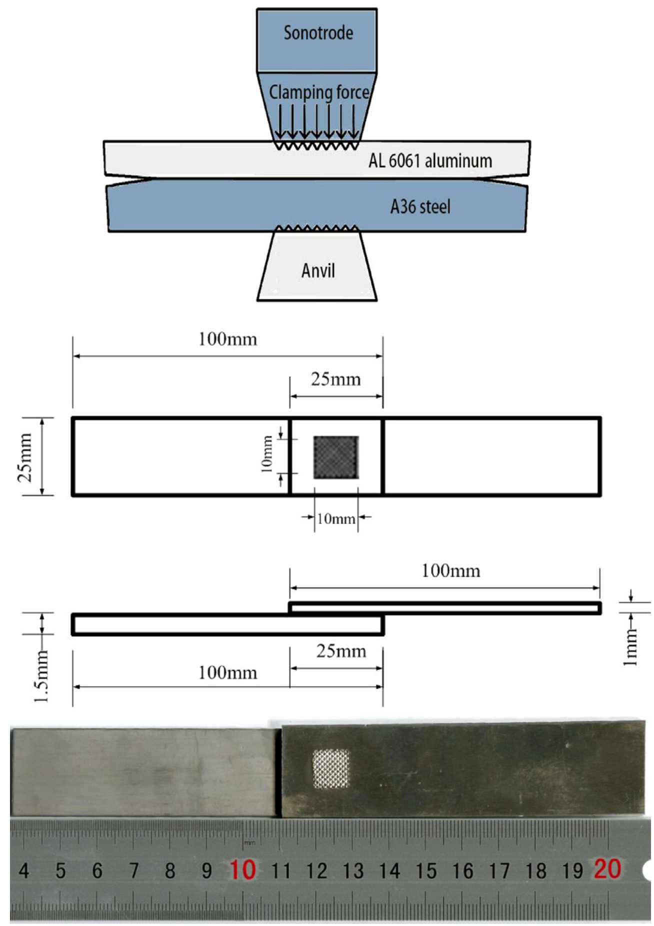


**Fig. 1.** Schematic diagram of ultrasonic welding and specimen dimension. Approximate weldment for tensile-shear test.

The parameter ranges have to be as large as possible in order to characterize the welding process over the maximum application field. Preliminary screening tests revealed the following findings: the bonding of aluminum-steel is difficult when the clamping pressure is less than 0.2 Mpa (even if under the condition of high welding time and high welding amplitude); the joint strength is close to 0 due to collapses and cracks on the top surface when the clamping pressure is higher than 0.5 Mpa; a joint of high strength is obtained when the vibration time is about 500 ms; the specimen sticks to the welding head severely when the time is more than 3000 ms. For the ultrasonic welding equipment used in this experiment, the vibration amplitude can be adjusted from 20 to 40 μm. Based on the preliminary findings and the equipment capability, 3 factors each at 3 levels were selected to conduct a comprehensive experiment. The factor level combinations are detailed in Table 1.

### 2.2. Test results and analysis

#### 2.2.1. The load-displacement curves and the failure model analysis

The factor level combinations and tensile-shear strength are shown in Table 2. It can be seen that clamping force, vibration