Materials and Design 108 (2016) 518–528

Contents lists available at ScienceDirect

Materials and Design

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

Understanding the role of welding parameters and tool profile on the morphology and properties of expelled flash of spot welds

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ARTICLE INFO

Article history:
Received 28 May 2016
Received in revised form 4 July 2016
Accepted 5 July 2016
Available online 07 July 2016

Keywords:
Friction stir spot welding
Expelled flash properties
Flash morphology
Aluminium alloy
Welding parameters
Tool profiles

ABSTRACT

Stir zone galling, excessive deformation and degraded weld strength are attributes of friction stir spot welds with excessive flash. In an attempt to determine the critical expelled flash required to maximize weld strength of joints, an experimental investigation of the role of welding parameters and tool profile on expelled flash properties of spot welds of 1.6 mm thick AA2219-O alloy was carried out. The flash properties examined are pushed out length, thickness and resultant volume of expelled flash. The result shows that tool profile greatly influences the volume and morphology of expelled flash. Equally, the expelled flash properties were observed to be influenced by process parameters. However, the overall volume of expelled flash is affected by two process parameters which are tool rotational speed and plunge depth. The percentage contributions of plunge depth are 64.18% and 62.54%, and those of rotational speed are 20.25% and 32.83% in pinless and conical pin welds respectively. A nonlinear relationship exists between lap shear failure load of joints and ejected flash volume in all weld. A somewhat linear relationship is observed to exist between the expelled flash volume and the estimated stir zone energy at peak temperature in both pinless and conical pin welds.

1. Introduction

An essential phenomenon in friction stir spot welding is the flow of hot plasticized material. During friction stir spot welding (FSSW) of lightweight alloys, stirring (rotational), intermixing or intermingling, vertical and horizontal motions of plasticized material ensue [1–3]. As a result, a significant amount of the plasticized material is retained within the bulk material of the overlapped sheet while a section of the deformed material flows out of the stir zone as flash. The flow of material within the bulk material of the work-piece has been characterized by a lot of researchers through the use of tracer materials. For instance, A. Gerlich et al. [3], Hidetoshi Fujii et al. [4], Y.H. Zhao et al. [5], and B. Madhavi et al. [6] have investigated material flow of friction stir spot welds of 5754/6061 and 5754/6111, ADC12 aluminium die casting alloy, AA2014, and AA5052-H32 alloys via the use of tracer material technique respectively. However, the ejection of plasticized material (flash) out of the stir zone has been left utterly uncharacterized. Thus, the assessment of tool profile on expelled flash morphology, the role of welding parameters on expelled flash volume, and the relationship between flash volume and joint strength are open research windows that have not been thoroughly expounded in literature. Existing literature is based on varying welding parameters to improve weld strength without considering the amount of expelled surface flash.

In actual fact, material flow in FSSW or FSW has been classified as either an insufficient material flow (too cold a welding condition) or an excessive material flow (too hot a welding condition) [7]. Volumetric or void formation, minute flash and non-bonding are the most notable defects that accompany a too cold welding condition whereas large mass of flash, surface galling, nugget collapse [8], local melting [9] and degradation of mechanical properties of joints ensue during a too hot welding condition [7]. In fact, P. Podržaj et al. [10] affirm that large mass of flash is formed during friction stir welding due to excessive heat input. Excessive heat generation establishes thermal softening in the work-piece material beyond the tool shoulder boundary. Consequently, the tool shoulder loses its ability to effectively contain the material beneath the shoulder surface but it rather facilitates the expulsion of material in the form of excessive surface flash [7,8]. Thus, an optimum heat generation (or flow of plasticized material) that will ensure a minimum level of expelled flash, nugget integrity, and acceptable weld strength is the utmost focus of friction stir spot welding process.

However, flash is described as the circumferential collar of expelled-plasticized material formed around the circumferential edge of the indented tool shoulder cavity during friction stir spot welding process. It is clearly expressed as the material squeezed out of the shoulder to form a circular protrusion of plasticized material on the upper sheet

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http://dx.doi.org/10.1016/j.matdes.2016.07.013
0264-1275/

Table 1
Chemical Composition of AA2219-O aluminium alloy (wt%).

Alloy	Al	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	V	Zr	Others
2219-O	Bal	0.06	0.14	6.6	0.32	0.02	0.00	0.03	0.04	0.06	0.13	0.03

by Q. Yang et al. [2]. The vertical plunging of the rotating non-consumable tool into the work-piece material raises the temperature of the tool-material contact area via the generated frictional and deformational energy. Thus, the induced thermal energy softens the material of the stir zone and facilitates material flow into the bulk work-piece material (as penetrated material) and out of the stir zone (as expelled flash) during the FSSW process. However, one of the inherent defects of friction stir spot welding is the expulsion or ejection of hot plasticized material as flash during the welding process. Excessive flash has been affirmed by many researchers to be detrimental to the integrity of welds. In fact, excessive flash makes weld have unacceptable visual appearance even if the weld has acceptable weld strength [10]. Presently, there is no detailed information about the actual role of welding parameters and tool geometry on flash ejection during friction stir spot welding. A few existing literature resources that have tried to examine the amount of flash formed during friction stir spot welding processes are based on visual judgement or assessment of flash. For instance, W R Longhurst et al. [11] affirms that too much axial force is responsible for increase in the amount of flash due to tool digging into the work-piece.

In terms of cost-effectiveness, the removal of expelled flash from the surface of work-piece attracts some machining cost and time. The conventional way of removing flash formed during friction stir spot welding is by milling or grounding off the formed flash. Masakuni Ezumi et al. [12] invented and patented flash removal procedure during friction stir welding via a welding tool provided with a cutter [12]. Likewise, Rosal David et al. [13] invented and patented material surface modification using friction stir welding hybrid process. A high melting temperature material was employed as cutting elements located on the outside diameter of a collar assembly retrofitted to the welding tool. Thus, flash and blurr created during friction stir welding are removed with the aid of the cutting elements [13].

On the other hand, many papers have shown that tool modification and changing welding parameters significantly influence the integrity of friction stir spot welds [14]. However, the roles of the salient FSSW parameters on expelled flash are still unclear. In an attempt to examine the integrity of welds via the assessment of flash, this paper classifies flash morphologies of welds formed under varying tool geometries, examines the role of welding parameters on expelled flash volume, and identifies the critical flash volume at which maximum weld strength is attained in friction stir spot welds of AA2219-O aluminium alloy.

2. Material and methods

Rolled plates of 1.6 mm thick Alclad 2219-O aluminium alloy were supplied by an aerospace material specialist known as AMI Metals Turkey, a subsidiary of AMI Metals Incorporation for this research. The chemical composition of the alloy as specified according to ASTM E1251 standard and mechanical properties of the alloy as specified according to ASTM E8/B557 are shown in Tables 1 and 2 respectively. As a result, prior to the actual welding, the as received 1.6 mm thick AA2219-O aluminium alloy plates were cleaned with acetone and cut into the desired sizes through the use of hydraulic guillotine machine. Also, HSS was employed in fabricating two forms of tool profiles on a lathe machine. A conical pin tool (CPT) and a pinless tool (PT) were fabricated. The conical pin had shoulder diameter, pin base, pin tip and pin height of 10 mm, 6 mm, 3 mm, and 2.47 mm respectively. The featureless flat tool (pinless tool) had shoulder diameter of 10 mm.

Table 2
Mechanical properties of AA2219-O aluminium alloy.

Ultimate tensile strength (MPa)	Yield strength (MPa)	Elongation %
146	63	22.3

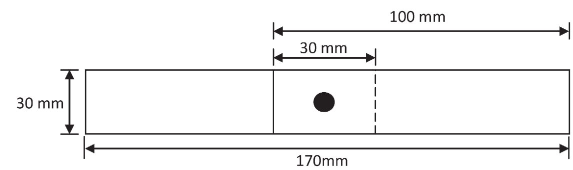

Fig. 1Please check all figure captions if correct and amend if necessary. Geometry of friction stir spot weld.

The overlapped work-piece geometry designed for the experiment is illustrated in Fig. 1. A CNC milling machine was adopted for the friction stir spot welding process. Firm clamping of the work-piece to the designed bed for the welding process was carried out before each weld trial. The outcome of the trial experiment was employed in selecting the parameter levels for the research. Thus, tool rotational speeds varying from 1400 to 1600 rpm, shoulder plunge depths varying from 0.43 to 0.8 mm and dwell times varying from 4 to 8 s were employed as process parameters for the actual experiments. Taguchi design of experiment was utilized to plan for the experiment and L9 orthogonal arrays were adopted for the experiment as shown in Table 3. Typical joints produced with pinless and conical pin tools are shown in Fig. 2. On the other hand, the lap shear failure loads of welds were obtained by using a 30kN computer controlled Zwick tensile machine in accordance with TS EN ISO 6892-1 standard. A displacement rate of 0.5 mm/s was applied on the test specimens until complete separation of the specimens.

In order to determine the overall volume of expelled flash in each weld, the assessments of joints made with conical pin and pinless tools were carried out. The morphological illustrations of welds obtained with pinless tool and a conical pin tool are shown in Figs. 3 and 4 respectively. Thus, the pushed out lengths and thicknesses of flash are the quantifiable flash features of welds. These features were measured with the aid of digital callipers; the jaws of the callipers were efficient in measuring the pushed out lengths of the flashes while the slender depth probe of the callipers facilitated the measurement of the flash thicknesses. In measuring the flash thicknesses, the main scale bar of the caliper was positioned to rest on the flash while the movable probe was pushed downwards to reach the surface of the work-piece material prior to each reading. Likewise, in situations where the breaking of the serrated flash was not up to the root of the ring flash, a section of the serrated flash was sheared off to facilitate the positioning of probe tip for the measurement of thicknesses of the ring flash in conical pin welds. However, the difficulty in estimating the resultant pushed out length of the serrated flash (SF) in conical pin welds was eliminated by adopting approximate pushed out length for SF. The approximate pushed out length was the average of the minimum and maximum

Table 3
Orthogonal array for the experiment.

	A	B	C
Exp. no.	Rotational speed (rpm)	Shoulder plunge depth with CPT (Penetration with PT) (mm)	Dwell time with CPT (dwell time with PT) (s)
1	1400	0.43 (0.43)	4 (4)
2	1400	0.45 (0.45)	5 (5)
3	1400	0.48 (0.80)	6 (8)
4	1500	0.43 (0.43)	5 (5)
5	1500	0.45 (0.45)	6 (8)
6	1500	0.48 (0.80)	4 (4)
7	1600	0.43 (0.43)	6 (8)
8	1600	0.45 (0.45)	4 (4)
9	1600	0.48 (0.80)	5 (5)