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ScienceDirect

Procedia CIRP 67 (2018) 440 – 445

www.elsevier.com/locate/procedia

11th CIRP Conference on Intelligent Computation in Manufacturing Engineering, CIRP ICME '17

In-process control of rotational speed in friction stir welding of sheet blanks with variable mechanical properties

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Abstract

In the present work, an adaptive control constraint system was applied in the friction stir welding of AA6082 aluminum alloy with the aim of tailoring the mechanical properties of the sheet blank to the subsequent forming processes. To this purpose, blanks in the solution heat-treated and artificially aged (T6), and in the annealed (O) conditions were welded according to a well defined layout. Such in-process control strategy was based on the variation of the controlled variable (rotational speed of the pin tool) in order to keep the measured one (vertical force) constant during the welding stage of the process. To this end, a preliminary investigation on the effect of the rotational speed, varying from 1000 to 2500 rpm, on the vertical force during FSW was performed. The capability of the proposed approach in friction stir welding sheet blanks with variable mechanical properties along the welding line was proven.

Peer-review under responsibility of the scientific committee of the 11th CIRP Conference on Intelligent Computation in Manufacturing Engineering

Keywords: Friction stir welding; Aluminum alloy; Temper state; Adaptive control

1. Introduction

Friction Stir Welding (FSW) is considered as one of the most promising technologies to obtain Tailored Welded Blanks (TWBs), that are semi-finished components consisting of at least two single sheets welded together prior to the forming process [1, 2]. The attitude of FSW in the obtaining of TWBs is related to the solid-state nature of the process that allows the avoidance or the severe reduction of the typical defects taking place during fusion welding techniques [3, 4]. In friction stir welding process, a rotating pin tool is inserted into the edges of the sheets to be joined, producing a stirring action, until the tool shoulder contacts the top surface of the sheets with a given plunge depth, thus generating a large amount of heat by friction. Then, the translation of the tool along the welding line allows the obtaining of the weld seam. Such features make FSW suitable to join alloys, considered un-weldable or difficult to be welded, with high levels of joint efficiency [5, 6].

TWBs are mainly developed in order to improve the properties of parts for their applications and to contribute to the weight reduction, that is particularly marked as they are made in low density and high strength alloys [7]. In spite of these advantages, problems can arise as the tailored welded blanks are subjected to sheet forming processes due to their nonuniform thickness and/or strength. In such applications, the TWBs can be replaced by the Tailored Heat Treat Blanks (THTBs) developed to allow an enhancement in formability [8, 9]. A THTB is obtained by subjecting the sheet blank to a local heat treatment in order to tailor the mechanical properties to the subsequent forming processes instead of the final application. The most used materials are precipitation hardening aluminum alloys and high strength steels. The critical aspect in the production of the THTBs is the heat treatment in terms of stability, robustness, layout, occurrence of heat affected zones, and heating technology.

Peer-review under responsibility of the scientific committee of the 11th CIRP Conference on Intelligent Computation in Manufacturing Engineering
doi:10.1016/j.procir.2017.12.239

An alternative process to improving formability in localized zones of sheet blanks could consist in friction stir welding blanks subjected to different heat treatments and positioned according to a suitable layout, defined taking into account the subsequent forming processes. Since FSW is performed by joining dissimilar materials or materials with mechanical properties variable along the welding line, the choice of the process parameters is the most critical aspect in order to obtain desired results [5]. The utilization of an in-process control strategy, able to adjust the process parameters on the basis of mechanical properties of the materials being welded, can strongly increase the success of the FSW of blanks subjected to different treatments. Recently, a method was developed in FSW of AZ31 magnesium alloy sheets with variable thickness along the welding line; it consists in adjusting the rotational speed of the pin tool in order to keep constant the vertical force (F) during the welding stage of the process [10]. If the F value corresponds to the condition that provides the best mechanical properties of the joint, the FSW process of blanks subjected to different temper states is optimized.

In this framework, the present work deals with the application of an in-process control strategy in the friction stir welding of AA6082 aluminium alloy in two different states, namely in the solution heat-treated and artificially aged (T6), and annealed (O) states. Such approach is based on the variation of the rotational speed of the pin tool in order to keep the vertical force constant during the welding stage of the process. The experimental tests have proven the capability of the proposed approach to join at high efficiency sheet blanks with variable mechanical properties along the welding line.

2. Material and experimental procedures

Friction stir welding experiments were performed on a CNC machining center. The 2 mm thick sheets in AA6082 aluminium alloy, supplied in the solution heat-treated and artificially aged (T6), were cut into blanks, 60 mm in length, and 80 mm in width; then, part of them were subjected to the annealing heat treatment (O).

The FSWed blanks were obtained by means of a two-step process. In the first step, dissimilar joints were obtained by welding two blanks in T6 and O states; the blank in the T6 state was positioned in the advancing side (Fig. 1a). In the second step, the dissimilar joints were assembled according to the layout shown in Fig. 1b in order to weld blanks with variable mechanical properties along the welding line.

Experiments were carried out by equipping the machining center with an adaptive control constraint (ACC) system that allows to adjust the rotational speed (ω) of the pin tool with the aim to keep the vertical force (F) arising during the welding stage of the process at a value depending on the mechanical properties of the material being welded. The F value was measured by means of a sandwich dynamometer, developed by Forcellese et al. in [11], consisting in three piezoelectric one-component force sensors fitted between two rigid plates with a high preload (Fig. 2).

A preliminary investigation on the effect of the rotational speed on the vertical force during FSW was also performed. To this purpose, FSW experiments were carried out for the obtaining of similar joints both in the O and T6 states (Fig. 1c); different rotational speeds, varying from 1000 to 2500 rpm, were investigated with a constant welding speed equal to 60 mm/min.

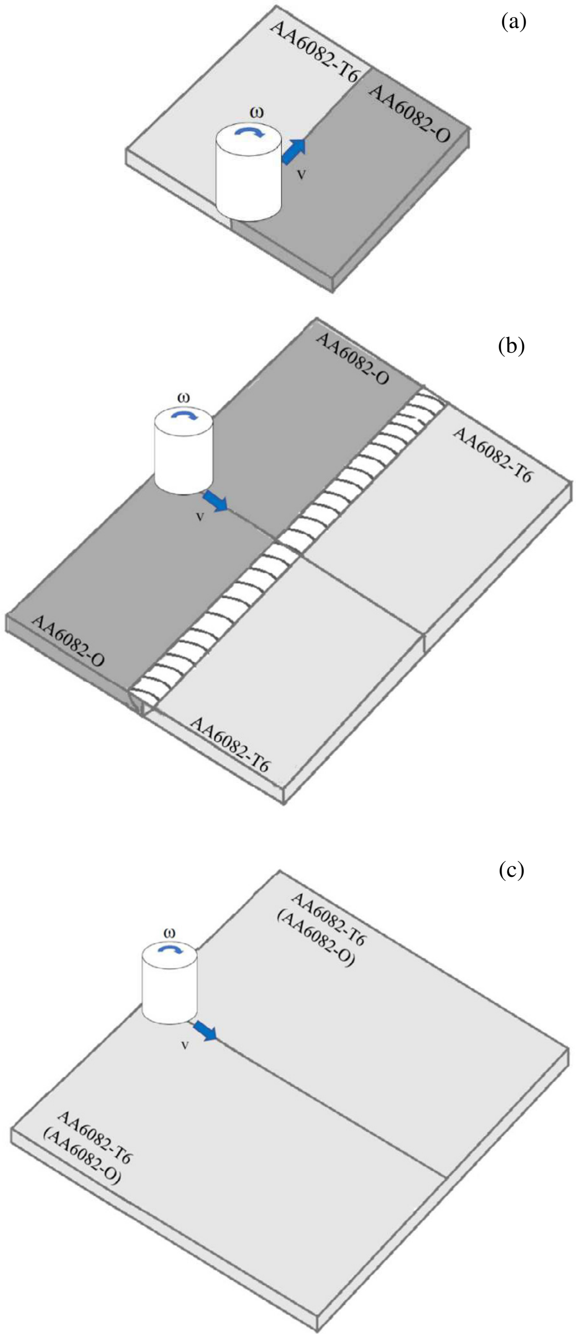

Fig. 1. (a) Positioning of the sheet blanks in FSW of dissimilar joints; (b) positioning of dissimilar joints in FSW of blanks with variable mechanical properties along the welding line; (c) positioning of blanks in FSW of similar joints.