

Eds analysis results of the wear surfaces engineering essay

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Abstract

Friction welding process is a solid state welding method that produces a joint under the compressive force makes contact with of one revolving and one motionless work piece. The solid state welding process it produces joints with reduced distortion and better mechanical properties. The titanium alloys are broadly used in special industrial applications such as shipbuilding, automobile industries and nuclear industry because of their special metallurgical and mechanical properties. In this work, friction welding of Titanium alloy rods of 10mm diameter was investigated with an aim to understand the limits of process parameters on weld microstructure, macrostructure and tensile strength. To attain the maximum tensile strength of these joints using response surface methodology and optimize the friction welding parameters. The designed model was checked by ANOVA technique. The details of ultimate tensile strength and microstructure analysis using optical microscopy are discussed. Keywords: Ferrous metals and alloys, Welding, Titanium alloy (Ti-6Al-4V alloy), Friction Welding, Tensile strength, ANOVA, Mathematical model.

1 Introduction

Friction welding is a process in which the heat for welding is produced by direct exchange of mechanical force to thermal energy at the edge of the work-pieces without the application of electrical power source or heat from other sources to the work-pieces [1]. R. G. ELLIS, Continuous drive friction welding of mild steel. *Welding J.* April, 183 (1972). Owing to the heat, the material reaches the plastic state, at which the plasticized material begins to

form layers that intervene with one another and results in good quality joint. To produce the good quality weld it is important to set up the proper welding parameters. The welding process is a multi-input and multi-output process in which welds are closely associated with welding process parameters.

Therefore, identifying the suitable combinations of process input parameters to produce the desired output require many experiments, making this process time consuming and expensive []. Kalyanmoy, D., 1996.

Optimizations for Engineering Design – Algorithm and Examples. Prentice Hall of India, New Delhi, pp. 290–333. The advantages of friction welding is one of the cheapest method to run, highly productivity, higher material safe, lower fabrication time and making the joining of parts, which are made of different alloys or metals possible. Friction welding process can also be used in welding of components that have round or noncircular cross-sections. The most interesting parameters in friction welding process are friction pressure, friction time, forging pressure, forging time and rotation speed [2]. Mumin Sahin. Joining with friction welding of high-speed steel and medium-carbon steel. J Mater Process Technol 2005; 168: 202–210. Ti-6Al-4V alloy is one of the most essential titanium alloys and extensively used in aerospace industries. This alloy has brilliant corrosion resistance and fracture toughness. Also, it can be readily welded, machined and forged []R. Roger, E. W. Collings and G. Welsch: Materials Properties Handbook: Titanium Alloys, Materials Park, OH, ASM International, 1994. The response surface methodology was used to optimize the Friction Welding (FW) parameters for this research. It is a collection of statistical and mathematical techniques that are helpful for scheming a set of experiments, analyzing the optimum

grouping of input process parameters, developing a mathematical model, and expressing the values graphically []. Gunaraj V, Murugan N. Application of response surface methodology for predicting weld bead quality in submerged arc welding of pipes. *J Mater Process Technol* 1999; 88: 266–75.

Balasubramanian M, Jayabalan V, Balasubramanian V. Developing mathematical models to predict tensile properties of pulsed current gas tungsten arc welded Ti-6Al-4V alloy. *Mater Des* 2008; 29(1): 92–7.

Mahendran G, Balasubramanian V, Senthilvelan T. Developing diffusion bonding windows for joining AZ31B magnesium-AA2024 aluminium alloys. *Mater Des* 2009; 30: 1240–4. From the literature review [] it is understood that the most of the published information on friction welding of Titanium alloy (Ti-6Al-4V alloy) focused on microstructure analysis, corrosion behaviour and phase formation studies at the interface to evaluate the consequent influence on the strength and the processing map to find out the best quality weld. Some of the investigations were carried out on a trial basis to attain optimum joining conditions. Only a small number of research works have been reported to optimize the continuous drive Friction welding process parameters to attain the tensile strength of Ti joints. Chen Jian-chun, Pan Chun-xu Welding of Ti-6Al-4V alloy using dynamically controlled plasma arc welding process *Trans. Nonferrous Met. Soc. China* 21(2011) 1506-1512P.

Wanjara, M. Brochu, M. Jahazi, Ti-6Al-4V electron beam weld qualification using laser scanning confocal microscopy, *Materials Characterization* 54 (2005) 254– 262S. H. Wang, M. D. Wei, L. W. Tsay, Tensile properties of LBW welds in Ti-6Al-4V alloy at evaluated temperatures below 450 °C, *Materials Letters* 57 (2003) 1815– 1823A. Vairis, M. Frost, On the extrusion stage of

linear friction welding of Ti 6Al 4V, Materials Science and Engineering A271 (1999) 477–484 Yuhua Liu, Jiandong Hu, Yaping Zhang, Zuoxing Guo and Yue Yang, Joining of Zirconia and Ti-6Al-4V Using a Ti-based Amorphous Filler, J. Mater. Sci. Technol., 2011, 27(7), 653-658. R. Turner, J. C. Gebelin, R. M. Ward, R. C. Reed, Linear friction welding of Ti-6Al-4V: Modelling and validation, Acta Materialia 59 (2011) 3792–3803 To obtain the maximum strength, it is necessary to have complete control over the related process parameters. It has been proved by some researchers that efficient use of numerical design of experimental methods allows progress of an empirical methodology, to integrate a scientific approach in solid state procedures such as continuous drive friction welding and friction stir welding process []. Therefore, in this analysis an attempt was made to optimize friction welding process parameters to achieve maximum tensile strength in Titanium alloy (Ti-6A-4V alloy) rods via response surface methodology. Babu S, Elangovan K, Balasubramanian V, Balasubramanian M. Optimizing friction stir welding parameters to maximize tensile strength of AA2219 aluminium alloy joints. Met Mater Int 2009; 15(2): 321–30. Rajakumar S, Muralidharan C, Balasubramanian V. Optimization of the friction-stir-welding process and tool parameters to attain a maximum tensile strength of AA7075-T6 aluminium alloy. J Eng Manuf, 2010; 224: 1175–91.

2 Experimental works

Variety of trial runs were carried out with 10 mm diameter extruded rod of Titanium alloy (Ti-6A-4V alloy) to discover the feasible working limits of continuous drive friction welding process parameters. The chemical composition and mechanical properties of Titanium alloy (Ti-6A-4V alloy) are

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presented in Table 1 and Table 2. Different combinations of Friction welding process parameters were used to bring out the trial runs. Process parameters were carried out by varying one of the factors while keeping the rest of them at constant values. The working range of each Friction welding process parameter was determined upon by inspecting the macro and microstructure for a smooth appearance without any observable defects. The selected levels of the process parameters with their units and notations are presented in Table 3. Based on the trail test friction time and forging time is kept as constant at 3 sec for all the experiments. The extruded rods of 10 mm in diameter were cut into the required sizes (length= 60 mm) by power hacksaw cutting machine. The design matrix selected to conduct the experiments was a central composite Rotatable ($k < 6$) design, which is shown in Table 4. An indigenously designed and developed a machine of rotary type continuous drive friction Servo controlled Friction welding machine (Model: Rexroth, R. V. Machine tools, Capacity: 20kN Tools) were used to fabricate the joints is shown in Fig. 1. The welded specimens were turned using a CNC lathe to the standard dimensions as shown in Fig. 2. The ASTM E8M-04 guidelines were followed in preparing the tensile test specimens. Three tensile specimens were prepared for each weld conditions to predict the transverse tensile strength. Tensile test was carried out on a 100kN electromechanical controlled universal testing machine (FIE-Blue Star, India; Capacity: 0-100KN, Model: Instron-UNITEK-94100). The specimen was loaded at the rate of 1. 5KN per minutes according to the ASTM specifications and the average of the three results is presented in Table4. The optical micrographs of interface region, heat affected zone and base

metals for experimentally predicted optimum process parameter are shown in Fig. 10. The photograph of tensile test specimen's before and after the friction welding and tensile test are shown in Fig. 3.