Materials and Design 103 (2016) 209–222

Contents lists available at ScienceDirect

Materials and Design

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

Optimization of process parameters for friction weld steel tube to forging joints

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ARTICLE INFO

Article history:
Received 19 February 2016
Received in revised form 19 April 2016
Accepted 20 April 2016
Available online 22 April 2016

Keywords:
Friction welding
Steel tube to forging joints
Tensile strength
Elongation
Petal test
Petal crack length

ABSTRACT

In this study, structural durability of continuous drive friction welding (CDFW) of steel tube/forging joints is inspected. The relationship between the welding parameters and the mechanical properties is developed by using response surface methodology (RSM). While keeping rotation speed constant, friction pressure, friction time, forging pressure and forging time are used as input variables, and the tensile strength, elongation (%) and petal crack length are selected as output variables. For setting optimum condition parameters, the desirability function is used.

According to the confirmation experiment, the difference between the values of tensile strength, elongation (%) and petal crack length, predicted by response surface curve and the experimental data for the maximum desirability is 1.06%, 13.37% and 2.44%, respectively. Furthermore, the predicted model looks reasonably accurate based on the analysis of variance (ANOVA). Using the response curve, one may estimate the tensile strength, elongation (%) and petal crack length for similar joints.

In comparison to previous studies, optimization of CDFW parameters for forging bracket to steel tube joints is investigated for the first time. Petal test for the optimization of friction welding is also utilized for the first time.

1. Introduction

Tubular section components produced by friction welding are widely used in automotive industry due to their structural stiffness, minimized weight and lower cost. Friction welding provides a greater advantage over the overall durability; as compared to traditional fusion welding methods. Friction welding is a solid-state welding process at which coalescence is accomplished with pressure at temperatures below the melting point of the materials being joined [1,2].

CDFW is being investigated by numerous researchers since the late 50s [3–14]. Relationship between the tensile strength and the welding parameters are investigated on medium carbon steel joints [5], medium carbon to austenitic steel joints [7,12–14]. The fatigue lifetime and fracture mechanisms are also analyzed for similar material joints [8,12,13]. The fatigue lifetime of the dissimilar material joints show similar behavior with the material, having weaker fatigue strength [7].

As shown in Fig. 1, CDFW occurs in five stages. First stage is “frictioning stage” which starts when two parts are in contact and then, rubbing starts at the weld interface (WI). Rotational speed is held constant at this stage, while a friction force is applied to the parts for appropriate rubbing to initiate the development of thermal energy. During this stage, the torque reaches from zero to its peak value. Axial shortening is very little at this stage [15,16]. The second stage starts after the initial peak torque is reached, and continues until the equilibrium stage. Axial shortening starts mainly during this stage due to gradual softening. The applied axial load causes the softened material to flow radially outwards to form an upset collar. Next stage is the “equilibrium stage”, during which resistive torque remains nearly constant. “Braking stage” follows the “equilibrium stage”. When the WI is heated and a predetermined amount of axial shortening takes place at frictioning pressure value, electric motor is turned off and braking is applied. As soon as the speed of the rotation starts to decrease, peak terminal torque value is obtained. When the relative movement between the two parts ceases, it then falls and reaches to a zero value. Last stage is “upset stage”, which starts before the braking stage is finished, by increasing the frictioning force to an upset force; it lasts until a predetermined time or reduction in length (i.e. burn-off length) is completed [15–18].

Variations in torque during welding cycle have a crucial effect on the rate of heat generation, which consequently leads to an effect on the strength and quality of the weld. Usually, this torque curve includes small fluctuations due to surface finish, because the contacting surface of two members being welded have a finite surface roughness and the state of these surfaces is a function of the process used to create them, e.g. turned, rolled, and ground. It is followed by a deep tearing of the mating surfaces during frictional contact of the rubbing parts [16].

The quality of a friction welding depends on welding input parameters. In other words, optimization of a friction welding is possible by managing the input parameters to obtain the desired response. Friction

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http://dx.doi.org/10.1016/j.matdes.2016.04.072

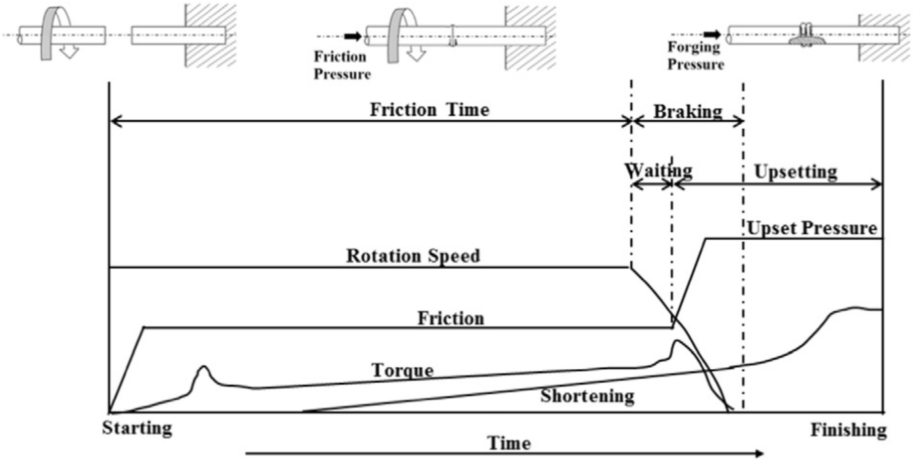

Fig. 1. CDFW process stages.

pressure, friction time, forging pressure, forging time, rotation speed and burn-off length are friction welding input parameters. Optimization of friction welding has been studied in the literature for combining several types of joints. For instance stainless steel rod joints, carbon steel rod to stainless steel rod joints, super duplex stainless steel (SDSS) rod joints, austenitic steel to copper alloy rod joints, aluminum alloy to stainless steel rod joints, carbon steel rod joints and titanium to stainless steel rod joints [19–29]. In the literature, optimum friction welding has been managed by measuring tensile strength, elongation (%), impact strength, corrosion current, and interface hardness of the joint and burn-off length. Statistical optimization techniques have been performed for the optimization procedures. In previous studies, the RSM has been chosen in order to obtain the optimum welding parameters. By this way, the input parameters are formulized to obtain the desired response [19–24]. Some of the researchers have applied the RSM to maximize the tensile strength of the aluminum to stainless steel joints. Friction pressure has been found the most significant factor on the tensile strength of this dissimilar material joint, followed by friction time, forging time and forging pressure [20]. RSM has also been used for investigating the tensile strength and interface hardness relations on stainless steel to copper alloy joints; where the rotational speed has been found the predominant factor [21]. In order to obtain a higher impact toughness and corrosion resistance, friction force, forging force and burn-off length of a SDSS joint have been optimized by using the Pareto optimization method where RSM and genetic algorithm (GA) have been utilized [22]. Furthermore, RSM has been applied to maximize the tensile strength of the carbon steel to stainless steel rod joints [23]. Stainless steel joints have been optimized by using artificial neural networks (ANNs) and GA, to obtain maximized tensile strength and minimized burn-off length.

Basically, there are two destructive techniques to test the quality of a welded joint; tensile testing and petal testing. Petal testing can be applied simultaneously as soon as the weld is completed. As per petal test, specimen is cut into petals; which are 10–12 mm wide longitudinal slices, transverse to the weld line, see Figs. 2 and 3. At the end, these petals are bent outwards with the help of a punch. Weld quality pass criteria is no visible crack and rupture at the welding interface [30,31].

Although forging parts are widely used in automotive industry, the investigations on friction welding for forging joints were limited [5, 11]. Particularly, there is no published data for the optimization of the friction welded steel tube to forging joints. Several researchers have been applied RSM to optimize the tensile strength of friction welded joints [19–24]. The tensile test usually represents a go/no-go bipolarity of answers, because fracture may occur on the base material (go) or along the heat affected zone (HAZ) and the weld interface (no-go). However, petal test crack length may provide a wider range of results, including partially cracked petals. The length of the cracks on these petals can be measured to quantify the weld quality. Previously, petal test has been applied by Phillips [30] to define the significant parameters of a magnetic arc butt welded chromium plated steel tubular joint.

The main objective of this study is to optimize the CDFW of steel tube to forging joints using RSM to achieve “good weld” with maximum mechanical properties. “Good weld” was defined as the welded joint which does not have excessive/burnt weld lips or non/partially developed weld joints or visible external defects. In comparison to previous studies, optimization of CDFW parameters for forging bracket to steel tube joints is investigated for the first time. Petal test for the optimization of the friction welding has been utilized for the first time. Optimum welding parameters for maximum tensile strength together with maximum elongation (%) and minimum petal crack length are demonstrated.

2. Experimental details

2.1. Materials

Forging bracket material used in the friction welding investigation was AISI 1045, and the material used for the tube was DIN 2394-ERD 9056, with an outer diameter of 68 mm and a wall thickness of 4 mm.

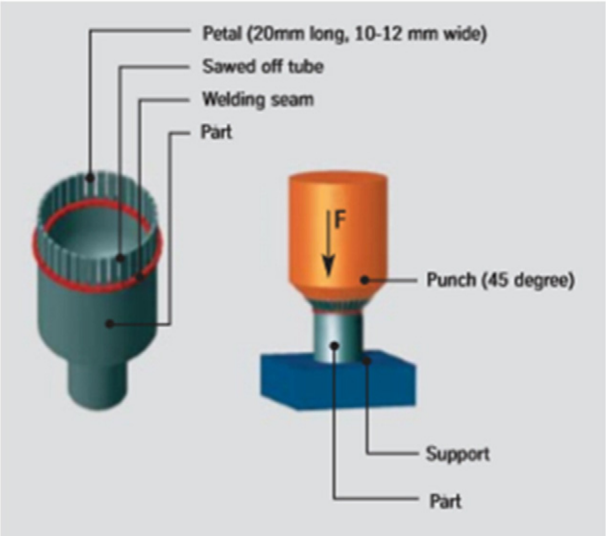

Fig. 2. Petal test procedure [32].