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Tube/tube joining technology by using rotary swaging forming method

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ABSTRACT

With the development of the manufacturing technology, a challenge has been proposed on the joining of difficult welding materials and the poor connection interface of materials. In this paper, rotary swaging technology is utilized as a joining by plastic deformation forming method to join tube/tube parts with different diameters. Experimental set-up of rotary swaging forming was designed and fabricated, in which the forging energy can be adjusted by changing the rotation speed of AC server motor. The rotary swaging model and tension testing model are established by using FE simulation software Forge 2D. The effects of forming parameters on the tension strength of the joined tubes and the joining mechanism are investigated. The results show that a concave arc joint can be formed at the overlapping parts of the tubes. To obtain the high joining strength, the distance from the end of the inner tube to the center of the hammer die need to exceed a certain value. The maximum strain and stress occur at the concave arc joining region in which the thickness variation of the two joined tubes is small. To exam the joining strength, the tension test was performed. The two tubes tend to slide out during tension process and the maximum stress occurs at the relative sliding region. The ratio on tensile load of the joined tubes to the maximum tensile load of the single tube can reach to 68% for the inner tube and 47% for the outer tube. Therefore, the joining strength of the tube/tube parts, formed by using rotary swaging method, is enough high.

1. Introduction

With the development of manufacturing technology, lightweight technology is widely used in automobile, aviation and aerospace industries, thus bringing a tremendous challenge on the joining of difficult welding materials and the poor connection interface of materials. The traditional welding technology can no longer be used for certain joining situations such as the joining of aluminum with titanium alloy, copper with superalloy and metal with composite. Therefore, some researchers have carried out the study on material joining by utilizing plastic deformation method. It is a competitive joining technology in industries, including all processes where parts being joined or involved, due to its advantages such as well joinability of different materials and high strength of the joint. Furthermore, compared with traditional welding or brazing, joining by forming method avoids heat input and produces very little heat, thus saving enormous energy resources and eliminating thermal influence on the material.

Due to the advantages of joining by forming method, some challenging works have been done. Mori et al. (2006) developed an effective method in combining the high strength steel and aluminum sheet by utilizing the self pierce riveting with an optimized shape of die. Alves et al. (2011) carried out a tube end forming method which was built upon the combination of compression beading with tube inversion. Alves and Martins (2013) proposed an innovative mechanical joining process for fixing sheet panels against tubular profiles with a single ram stroke. Kitamura et al. (2012) studied a plastic cold joining method of a rotor shaft with a flange which can be developed to fabricate automobiles axle parts. Matsumoto et al. (2008) investigated a newly developed plastic joining method 'indentation joining' for fixing a cold bar with a hot forged plate. Neugebauer et al. (2008) studied a mechanical joining method for joining magnesium parts by dieless clinching. Marre et al. (2008) examined the feasibility of combining joining tubular workpieces by expansion (using rolling and dieless hydroforming) and joining by compression (using external rolling and electromagnetic compression) with adhesive bonding. Huang et al. (2013) proposed a hybrid of chemical bonding and plastic deformation joining process for thin metallic and continuous carbon fiber reinforced thermosetting plastic sheets. The results indicate

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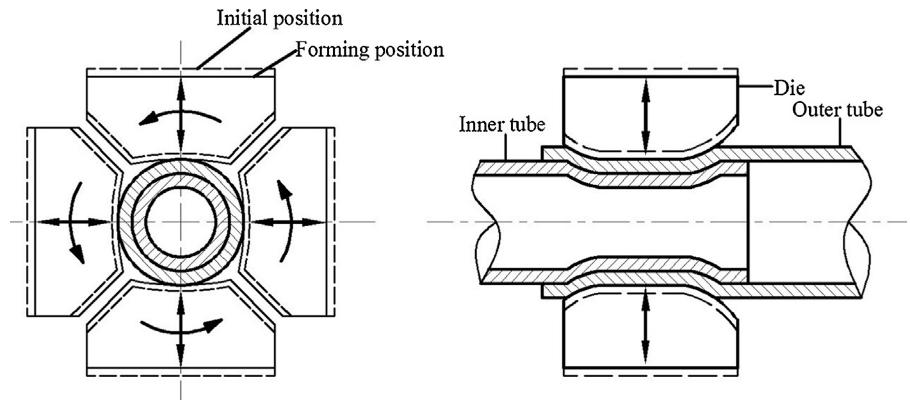

Fig. 1. Schematic representation of joining tubes with different diameters by rotary swaging.

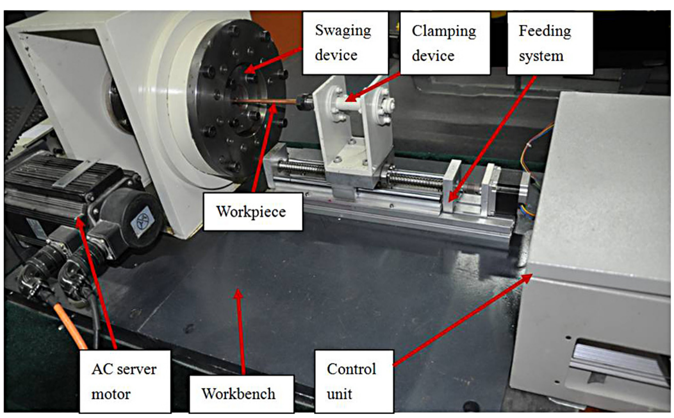

Fig. 2. The rotary swaging machine.

that adhesive-embossing hybrid joining method had potential as a competitive alternative joining method. Psyk et al. (2011) reviewed the electromagnetic forming method which can be applied for connecting tubes as well as sheet metal. Using this method, a tubular workpiece can be compressed onto an internal joining partner or expanded into an external joining partner. Alves and Martins (2012) developed a flexible and cost-effective tube branching process based on asymmetric compression beading which can successfully replace the conventional solutions based on commercially available or user made types of connections that require welding and brazing.

Rotary swaging technology originates from the United States in the 20th century. It is widely used in automobile and aviation industries due to its high cost effective and considerable material saving. Rotary swaging can be classified as a special type of the radial forging, which has been widely applied to the situations such as reducing the diameters of the ingots and bars, forging of the stepped shafts and forging of the rifle barrels (Ghaei et al., 2008).

Ghaei et al. (2006) presented a new upper bound solution considering three distinct regions of deformation in radial forging of the tubes to analyze the radial forging process. Sanjari et al. (2012) used finite element method and microhardness test to determine the strain field and heterogeneity of the tube in radial forging process. Abdulstaar et al. (2013) investigated the microstructure evolution and change in mechanical properties of commercially pure aluminum during severe plastic deformation by rotary swaging at the ambient temperature. Lim et al. (2009) conducted experiments using rotary swaging machine to investigate the forming characteristics of the tubular product such as hardness distribution and microstructure of the tube. Jang et al. (2012) analyzed the reliability for the occurrence of process-induced cracks which was performed by fault tree analysis indicating that a swaged shell nose part with higher reliability can be successfully produced by the rotary swaging process. Piwek et al. (2010) presented the production-orientated capabilities of light weight design to manufacture those components by rotary swaging process such as hollow shaft drives made from tubular material.

Rotary swaging technology has been studied by some researchers. However, according to the published literatures, the information about the joining technology by using the rotary swaging process is less. In this paper, joining by rotary swaging is utilized as a joining by plastic deformation method for connecting tube/tube parts. Both simulated and experimental methods have been used to investigate the joining mechanism and the deformation process of the tubes, as well as the joining strength of tube/tube parts.

2. Experimental background

2.1. The principle of joining by rotary swaging

Rotary swaging, as an incremental forming process, utilizes three, four or in special case up to eight dies arranged concentrically around the workpiece. The forging dies move simultaneously in both radial and axial directions relative to the workpiece. The swaging dies perform the high-frequency radial movement with short strokes. The stroke frequencies range from 1500 to 10,000 per minute. The advantages of high-frequency stroking and multidirectional forging process contribute to the increase of plasticity and deformation homogeneity of materials. Based on these advantages, rotary swaging process favors the reduction of rods, tubes and ingots usually. It can also be applied to the tapering of rods, calibrating of precision tubes and joining of two workpieces. When

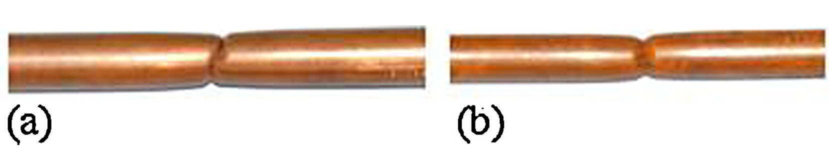

Fig. 3. Copper tubes after tension test: (a) ϕ8 tube and (b) ϕ6 tube.