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Technical Paper

Mechanical properties and fatigue behavior of electromagnetic riveted lap joints influenced by shear loading

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ABSTRACT

Electromagnetic riveting (EMR) has gained increasing attention as a relatively new mechanical joining technique in automobile industry. In this paper, the mechanical properties and fatigue behavior of electromagnetic riveted lap joints are discussed systematically. The rivet deformation, microstructure and hardness distribution of the formed rivets were investigated, which were also compared with regular pressure riveting (RPR). The results of shear strength showed that there was almost no difference between EMR and RPR, and the fatigue performance of EMR was about 1–3 times higher than that of RPR at any cyclic stress level. Quasi-static fracture analysis showed that shear fracture occurred in rivet shaft and the rupture appearance of two processes was similar. For fatigue failure, there were two fatigue failure modes for both processes: rivet shaft fracture under a higher cyclic stress and manufactured head fracture under a lower cyclic stress. Under the higher cyclic stress level, there was no big difference between two processes in the fatigue appearance. However, the fatigue cracks propagation zone of EMR sample fracture was significantly wider than that of RPR under a lower cyclic stress level, indicating a higher fatigue life of EMR samples.

1. Introduction

In automobile and aerospace manufacturing fields, the durability and security of machining parts are extremely important. Joining process as an inevitable assembling procedure is usually used in the sensitive area, and most strength failures occur in lap joints especially in transport aircraft [1]. Consequently, automotive body and aircraft fuselage consist of numerous lap joints which are attained by various joining techniques such as welding [2], bolting [3], and riveting [4]. However, welding defect caused by stress concentration and heat affected greatly reduce the joint reliability. By contrast, riveting process has some characteristics of reliable and stable joint quality, simple process, high efficiency and good seal [5].

Based on the advantages of riveting process, exhaustive studies have been conducted on the riveting lap joints. Hartman et al. [6] found that the rivet lap joints with a relatively higher rivet driven head diameter had better fatigue strength and Skorupa et al. [7] investigated the effect of the driven head dimensions of the rivets on the strength of riveted joints comprehensively. The hole expansion (namely interference) was defined as the gap between expanded rivet shaft and the original hole. Müller [8] firstly measured the riveting interference and found the maximum value occurred near the driven head. Skorupa et al. [9] proved that a suitable interference had better mechanical properties and fatigue performance. Newman et al. [10] explored microstructure in the rivet cross section of the riveted sample with countersunk rivets, and found that the cracks initiated and grew from the faying surface. Literatures mentioned above mainly focused on the rivet process parameters studies such as rivet driven head dimensions, interference and cracks initiation. However, there are still some defects for the conventional riveting methods, such as easy slanting, cracking of the driven head, lower impact force and powerlessness for the bigger diameter rivets. Alternative riveting approach for structures is electromagnetic riveting (EMR), the main theory of which is based on the high-speed electromagnetic forming (EMF) (strain rate of $10^4\,s^{-1}$ [11]) and regular riveting technology. As a new riveting method, EMR has been proved to have many advantages such as higher efficiency, the high-speed loading and the larger impact force. The advantage of EMR can further improve the joining quality of riveting lap-joint structures. For

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example, Cao et al. [12] studied the interference in fiber composite riveting structures. The results showed the EMR technique had a better-distributed interference than hydraulic squeeze riveting and could partly prevent the destruction of the composite laminates. Experimental results obtained by Feng et al. [13] showed that both shear strength and pull-out strength of the EMR structures were significantly higher than that of the pneumatic riveting. Zhang et al. [14] investigated that the effect of driven head dimensions on microstructure and mechanical properties, and also found that Φ10 mm-2A10 electromagnetic riveted structures could not only improve both shear strength and pull-out strength, but also reduced the total weight compared with Φ6 mm-30CrMnSi bolted structures. Adiabatic shearing deformation is the significant characteristics of EMR, which could affect the microstructure properties in rivet driven heading and the strength of the rivet joints. Choo et al. [15] found that the high strain rate induced the precipitation hardening in adiabatic shear bands (ASBs) and led to the failure of aluminum rivets. Deng et al. [16] demonstrated that the deformation mechanism of EMR was the adiabatic shearing deformation and results from experiments and simulations showed that the maximum temperature was in ASBs of titanium alloy rivets. Zhang et al. [17] discovered that the driven head was divided into several zones with different mechanical properties by ASBs.

Aforementioned work have mainly addressed the technical index (e.g. the interference) and the deformation mechanism in driven head, as well as its influence on the mechanical properties (e.g. shear and pull-out strength) of the EMR structures. The mechanical properties could only be used to evaluate the one-time or short-term bearing capacity of the structures, whereas the long-term performance evaluation in the industrial application usually adopts fatigue strength. However, few studies on the fatigue properties of EMR structures have been done so far. In addition, the relationship between the rivet deformation and microstructure after EMR has not been fully discussed.

The aim of this paper is to investigate the rivet deformation mechanism, joining strength of carbon steel lap joints and the relationship between the two during the EMR. In addition, regular pressure riveting (RPR) with a quasi-static speed (2 mm/min) was employed to use as the comparing process. Firstly, the rivet deformation were measured after riveting, including rivet driven head dimensions and the hole expansion values of riveted sheets. And then the microstructure observation was conducted to understand the microstructure evolution and hardness distribution of the deformed rivet. After that, experiments were performed to test the strength of the riveted lap joints, including shear and fatigue strength. Subsequently, the failure fractures appearance of shear and fatigue test were observed. Finally, the experimental results were analyzed and discussed. In general, this study is expected to provide further understanding of EMR and RPR lap joints for engineering application.

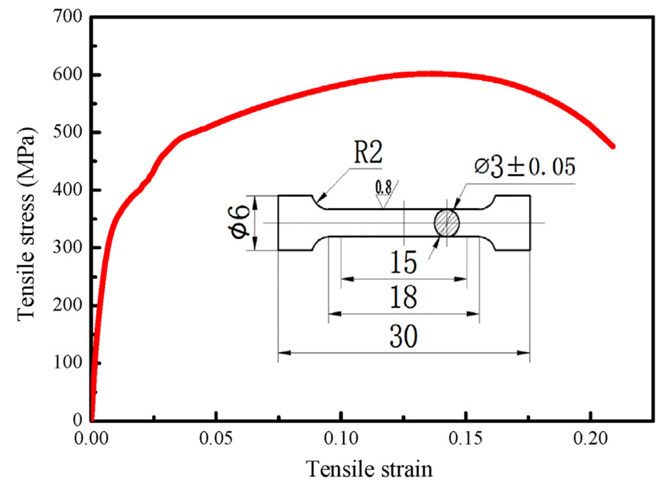

Fig. 1. The tensile stress-strain curve of Q235 carbon steel.

2. Materials and methods

2.1. Sample preparation

Q235 hot rolling carbon construction steel rivets (similar to SS41 carbon steel for ISO standard) were used in this study. Oldersma [18] found that the galvanic corrosion between dissimilar materials would usually occur. Therefore, the same materials were selected as riveted sheets. Material properties of rivets and sheets are presented in Fig. 1, which are obtained by quasi-static tensile tests with a 2 mm/min velocity. The main chemical compositions are presented in Table 1.

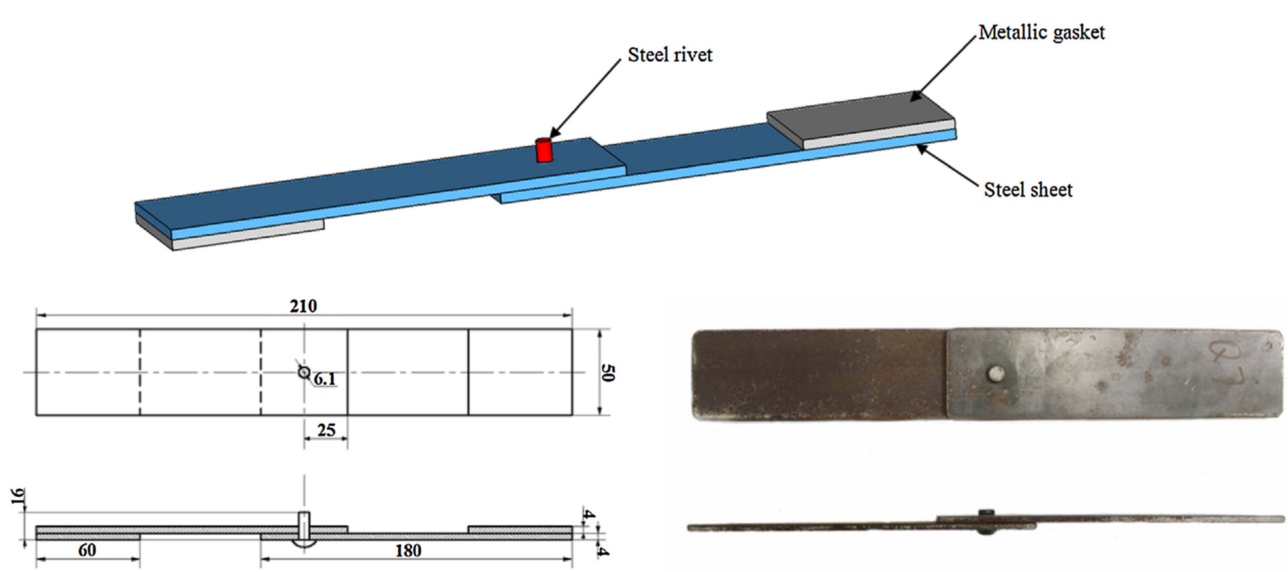

Fig. 2. Geometry and dimensions of the riveted specimens.