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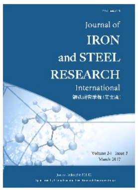

Effect of hot/warm roll-forming process on microstructural evolution and mechanical properties of local thickened U-rib for orthotropic steel deck

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ABSTRACT

To improve the strength-toughness of traditional U-rib (TUR) and solve the problem of insufficient penetration between TUR and deckplate, a new local thickened U-rib (LTUR) has been proposed to improve the fatigue resistance of the weld joint under the premise of not increasing thickness and strength of the TUR material. And a hot/warm roll-forming process (RFP) adopting partially induction heating to 700－1 000 ℃ was carried out to fabricate LTUR. The deformation behaviors in the forming process and microstructure of LTUR have been investigated. Mechanical properties and fracture mechanism of the LTUR after hot/warm RFP have been systematically discussed. Moreover, the results are compared with those obtained in cold RFP. Mechanical properties of the LTUR deformed above the critical transformation temperature (A_{c3}) show high performance characteristics with marked fatigue resistance and superior toughness. Upon increasing the heating temperature from 700 to 900 ℃, the initial coarse ferrite-pearlite structure transform into equiaxed ultrafine ferrite (1－3 μm) and precipitates such as (Nb,Ti)(C,N) are uniformly distributed in the matrix. The average dislocation density of the specimens after hot roll-forming at heating temperature of 900 ℃ decreases dramatically compared with those of the specimens subjected to the cold RFP. Furthermore, a typical characteristic of ductile fracture mechanism and the high impact energy are more convinced that the specimens deformed above 900 ℃ have obtained an optimal combination of strength and toughness.

1. Introduction

Since the middle of 20th century, the design level of steel box girder has been matured and the welding technique has been improved. The orthotropic steel deck system has been widely utilized for long-span steel bridges requiring light weight structures owing to its low depth, high strength and stiffness, easy processing and structural continuity[1]. This system consists of deckplate, crossbeams and U-ribs supporting the deckplate. Generally, the quantity of U-rib accounts for approximately 25% of the whole steel required of steel bridge design due to the high torsional stiffness and bending stiffness of U-rib[2]. Furthermore, it can effectively distribute an applied load on the deckplate. Therefore, U-rib is widely used in modern orthotropic steel deck system.

Orthotropic steel deck system belongs to thin-wall welding structure[3]. The welded joints between deckplate and U-rib in orthotropic steel deck system are potentially critical to fatigue failure due to stress concentration at the end of the weld toe[4]. The reason is the negative bending moments produced by live loads on the deck such as heavy weight trucks. Li et al. [5] pointed out that the fatigue cracks had often developed at welded connections of U-rib because of the large number of high magnitude axle loads, which lead to the fatigue life of orthotropic steel deck less than the designed service lifetime required by steel box girder. Wolchuk[6] suggested that the U-ribs should not be cut off and fitted between the floor beams. It is undoubted that transportation costs will increase and installation procedure will be more difficult. Xiao et al. [7] proposed to increasing the thickness and/or strength of U-rib material for reducing stress range and significantly increasing fatigue life of the welded joint. However, these methods exhibiting superior fatigue resistance have hardly been applied by bridge engineering for the reason

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of high costs. In addition, weight of bridge body will get greatly heavy if merely increasing the thickness of material.

The real reasons of fatigue cracks are that penetration depth is not sufficient because the welding process can only be implemented at the lateral side of U-rib and that the strength-toughness of traditional U-rib (TUR) material is low. According to the standards of AASHTO LRFD Bridge Design Specifications, Fatigue Design Recommendations for Road of Japanese, Design Specifications for Highway Bridges of Korean and Eurocode-3, the thickness and the penetration depth of U-rib are required not less than 8 mm and 80% of U-rib thickness, respectively. For the strength of U-rib material, 345 MPa grade steel widely used previously, such as SM490B, A572Gr50 or Q345qD, cannot meet the requirements of the development of steel box girder and is gradually replaced by a higher strength steel.

Studies[8-11] on enhancing the strength-toughness of metal by various methods to control the microstructure have been carried out. For high strength low alloy (HSLA) steel, grain refinement by means of plastic deformation at high temperature is feasible for producing excellent strength-toughness materials without any additive elements[12-15]. Hall and Petch[16,17] have explained the relationship between strength and average grain size by the Hall-Petch equation. Park et al.[18,19] proposed a heavy-reduction single-pass hot rolling process to enhance strength-toughness while the ductility was retained. They found that 0.2 wt.% carbon steel exhibited a superior combination between high strength and marked elongation after the plane-strain compression test above the critical transformation temperature A_{c3}. And the high-performance 0.2 wt.% carbon steel consisted of ultrafine or equiaxed fine grains with uniformly dispersed fine pearlite grains or cementite. The aim of this work is to present a processing technology for producing high performance U-rib with the similar above-mentioned microstructure at the edges without increasing thickness and strength of the whole TUR material. Moreover, the welding groove is improved. The microstructural evolution has been discussed in details via optical microscope (OM), field-emission scanning electron microscope (FE-SEM) and transmission electron microscope (TEM). More attention is paid to understand the relationship between mechanical properties and microstructure, precipitate as well as dislocation.

2. Experimental Procedure

2.1. Material and process

The investigated material, Q500qD, is a HSLA steel widely used in bridge engineering. According to Chinese standard GB/T 714-2008, the parent steel should have high strength-toughness, weldability and the ability of bearing loads and impact of vehicle. The chemical composition of the Q500qD steel is given in Table 1.

To solve the problem of insufficient penetration, a new U-rib structure is proposed for improving the fatigue resistance of the weld joint in this work, as shown in Fig. 1. And a hot/warm roll-forming process (RFP) model is developed to produce the local thickned U-rib (LTUR). This process model makes the microstructure and thickness of the LTUR edges different from other places instead of increasing the thickness and/or strength of the total U-rib material. Furthermore, the production costs of this new U-rib are not increased too much by replacing the traditional milling edges equipment using hot/warm roll-forming device.

Table 1

Chemical composition of investigated steel (mass%)

C	Si	Mn	P	S	Ti	Nb	Al
0.17	0.32	1.33	0.015	0.003	0.02	0.04	0.045

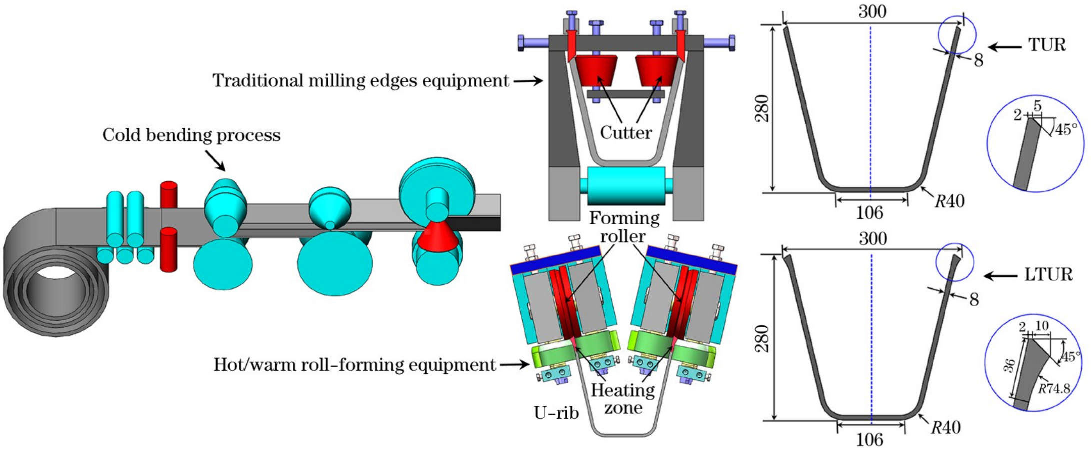

Fig. 1. Schematic diagram of traditional process and hot/warm RFP as well as sizes of TUR and LTUR (unit: mm).