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Grinding treatment effect on rib-to-roof weld fatigue performance of steel bridge decks

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ABSTRACT

To study the effect of grinding treatment on deck fatigue performance of U-rib and roof welds in steel bridge decks, eight specimens of U-rib and roof welds were manufactured. The shape and metallography of welded specimens were measured to ascertain their form, characteristics, and microstructure after grinding. The effects of weld grinding treatment on stress distribution and fatigue life were investigated by fatigue tests. The influence of grinding radius and depth on the local stress field was studied by finite element analysis, and suggestions for grinding treatment related to the gouge radius and depth were proposed. The results indicated that grinding treatment effectively increased the transitional radius of the welds and reduced the stress concentration thereon without changing the local microstructure. Local cracking resulted in stress redistribution with no change in the ultimate bearing capacity of the welds. Grinding treatment redistributed the stress on the U-rib to the deck weld, which improved the fatigue life thereof. Grinding treatment caused a reduction in the thickness of the deck, which resulted in an increase in bending stress. However, the stress concentration at the weld toe was diminished. The maximum stress was located at the bottom of the gouge after grinding and it decreased with increasing grinding gouge radius and increasing grinding gouge depth. The grinding treatment gouge sizes were suggested as 3 mm (radius) and 0.5 mm (depth).

1. Introduction

As the result of various factors, such as the imperfections in current fatigue design theory, increasing heavy traffic, initial imperfections and manufacturing errors and those arising during construction of steel box girders [1,2], the fatigue life of structural details in steel bridges is always problematic [3]. Once a fatigue crack occurs, it grows rapidly. The cracks cause fracture of steel components and reduce the performance of pavements. Moreover, water penetration causes deck corrosion. Although some crack repair [4] and reinforcement methods [5] can be applied to solve the problems of fatigue cracking, crack inspection works are required before repairs are affected [6]. Due to the wide distribution and quantity of welds, the inspection of fatigue cracks is onerous. The efficacy of any repair cannot be guaranteed without accurate crack detection. Moreover, the cost is huge. Fatigue cracks in a steel deck are difficult to avoid. Nevertheless, local treatment can reduce weld stress concentration and delay the onset of fatigue cracking.

There are many types of methods available to improve weld fatigue performance, including mechanical processing [7], laser- and shot-peening [8] and modification of spray fusing [9]. Most of these methods are applied only during manufacturing. This is mainly due to equipment, complexity, and operating environment demands. Grinding treatment technology can reduce stress concentration in theory because it bestows the advantages of portable equipment, low cost, and simplicity, and is less influenced by the surrounding environment and the weld position. Therefore, grinding treatment has been applied to various steel structures. The inspection of a marine engineering steel platform with grinding treatment on the connection weld of column brackets showed the welds were reliable [10]. The maintenance practices used for railroad in many countries prove that the effect of grinding treatment on preventing rail contact fatigue, controlling crack growth, and abrasion are reasonable [11,12]. Mechanical grinding is also one of the commonest methods applied to surface treatment of aluminium alloy welds in aerospace engineering, as it helps to improve material bonding properties, thereby, improving their fatigue and static performance [13]. Moreover, grinding is also applied in the polishing off of surface corrosion in the maintenance of aircraft structures.

Although grinding can improve fatigue performance, it is mainly applied to guarantee the quality of welding and remove corrosion at present. It is mostly considered as a method best used to remove surface flatness. In this study, grinding treatment was proposed to change weld shape partly to reduce the stress concentration caused by welding. Based on the results of fatigue tests and FEM analysis, the effect of grinding treatment on improving the fatigue performance of steel bridge deck welds was studied by comparing specimens and models with grinding or without. This work may provide guidance to those involved

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in welding, component manufacture, and fatigue maintenance of steel bridge decks.

2. Experimental programme

2.1. Specimens

Fatigue cracks on U-rib and roof welds are mainly caused by local out-of-plane transverse deformation of bridge decks and are located at both weld toe and root. Specimens of U-rib and roof weld were manufactured to simulate this detail. Fig. 1 shows the specimen sizes. The roof sizes were 600 mm length, 300 mm width, and 14 mm thickness. The U-rib sizes were 200 mm height, 300 mm width, and 8 mm thickness. There were eight bolt holes on the left side of the roof and four on its right to bolt the specimens to the fatigue test machine.

Table 1 shows the specimens in three groups: group SJ1 were those without grinding treatment and group SJ2 were ground. Each group of SJ1 and SJ2 contained three specimens. Group SJ3 was cut to compare the microstructural changes occurring. This group had two specimens with one ground and the other not. A Q345qD steel was adopted for the roof and U-rib of the specimens. The welding was done with reference to Chinese codes for “Welding electrodes and rods for gas shielding arc welding of carbon and low alloy steel (GB/T 8110-2008)” and “Carbon dioxide for weld (HG/T 2537)”. All specimens were welded by CO_2 gas metal arc welding technology. The angle between the roof and the U-rib was 78° with a tolerance of <1° thereon. All specimens were inspected by magnetic particle and ultrasonic (Level I) methods.

2.2. Grinding treatment process

Fig. 2 shows the requirements of the grinding treatment process. The grinder was run at 20,000 rpm. The top diameter of the grinder head was 4 mm. Grinding started from one end with a constant speed of 5 to 10 cm/min. The angle between the axial direction of the grinder head and the roof was 45° to 60° (Fig. 2(a)). The angle between the axial direction of the motion of the grinder head and the weld direction was 35° to 50° (Fig. 2(b)). A portion of roof and weld material was ground off to form a gouge along the centre of the weld toe (Fig. 2(c)). The grinding depth was 0.6 mm underneath the visible undercut with a general depth of <2 mm. If there was no undercut, the depth was 0.6 mm.

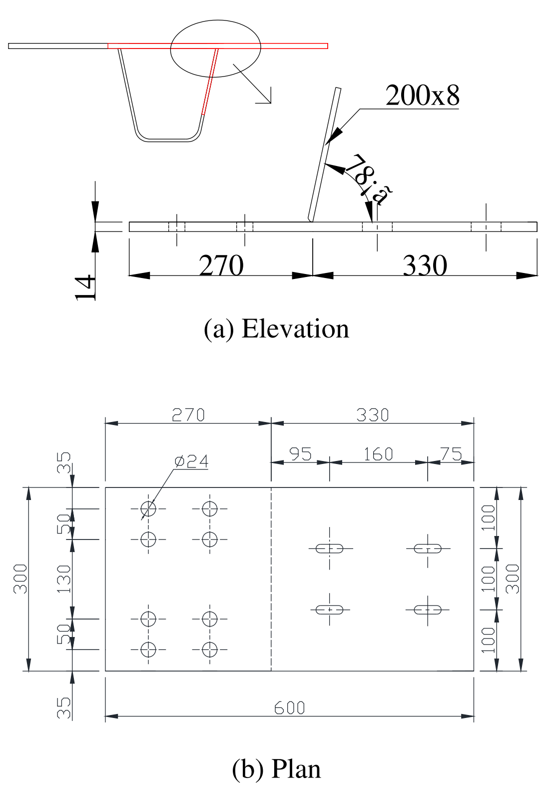

Fig. 1. Specimen size (units: mm). (a) Elevation (b) Plan

Table 1
Specimens and test results.

Specimens number	Treatment	Stress amplitude (MPa)	Fatigue life (cycles)	Notes
SJ1-1	No	100.9	4,177,100	
SJ1-2	No	100.9	2,243,700	
SJ1-3	No	101.4	2,429,400	
SJ2-1	Grinded	101.3	>10,000,000	No crack
SJ2-2	Grinded	101.1	>10,000,000	15 mm crack
SJ2-3	Grinded	100.9	2,585,300	–
SJ3-1	No	–	–	Metallographic test
SJ3-2	Grinded	–	–	Metallographic test

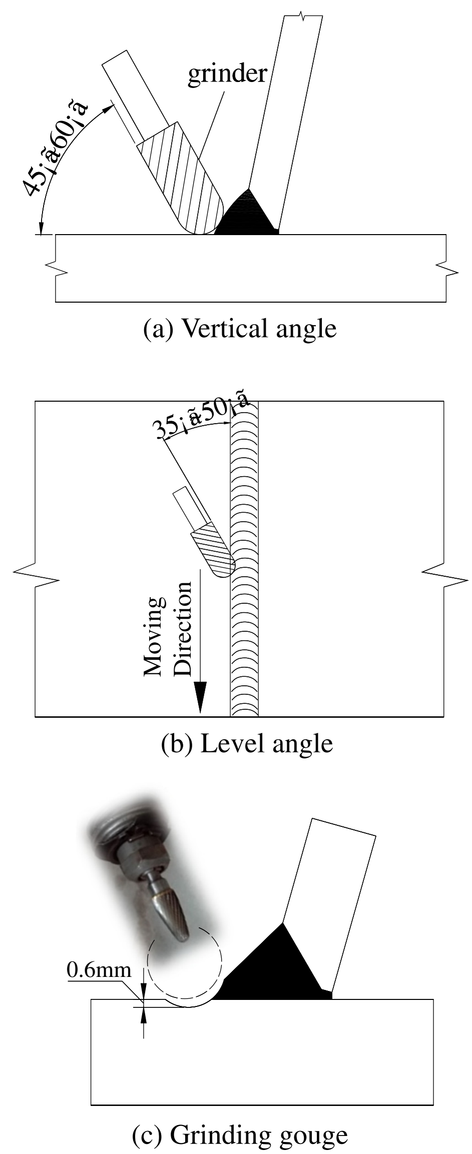

Fig. 2. Grinding treatment technology. (a) Vertical angle (b) Level angle (c) Grinding gouge