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Comparative investigation of the effect of corrosion on the mechanical properties of different parts of thin-walled steel

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ABSTRACT

To comparatively investigate the effect of corrosion on the mechanical properties of different parts of C-shaped thin-walled steel, the flat and corner parts of C-shaped steel purlin, with a service life of 9 years in an industrial environment, were processed into the tested specimens. The effect of corrosion on the cold-formed effect of C-shaped thin-walled steel was investigated by fracture morphology and stress-strain curves. Thus, three methods for calculating the yield strength of cold-formed steel with corrosion damage were also proposed. Finally, based on reverse reconstruction technology, ABAQUS software was used to analyse the effect of corrosion surface morphology on the stress distribution and for the same specimens with different thicknesses. The results showed that different fracture modes and characteristics occurred in both the flat and corner parts after corrosion, which can be attributed to the corrosion surface and thickness reduction. With an increasing degree of corrosion, the strength of the corner parts obviously decreased more than the strength of the flat parts. When the corrosion ratio was 36%, the yield ratio of the corner parts was as high as 0.99, and the elongation was only 2.8%. The corrosion aggravated the cold-formed effect on the strength and the ductility of cold-formed materials. In addition, the corrosion surface will lead to the unbalanced development of surface stress, resulting in the diversification of fracture paths and locations. Especially when the corrosion surface was more uneven with depth, the stress at the maximum corrosion depth was always greater than the stress at other locations. The effect of the corrosion surface on the mechanical properties was related to the residual thickness of the specimens and increased with thinner residual thickness.

1. Introduction

Cold-formed thin-walled steel, an economical light-walled steel, has developed rapidly in engineering because of its good cross-section properties, high utilization ratio and more favourable construction [1, 2]. Compared with the hot-rolled steel, the yield strength of the cold-formed thin-walled steel was increased by more than 50% due to the cold-formed effect, which can save the steel approximately 10%–15% [3–5]. Previous studies of the cold-formed steel were focused mainly on the calculation method and seismic performance of the uncorroded cold-formed thin-walled steel [6–8] and the effect of high temperature on the mechanical properties of steel [9–11]. However, avoiding corrosion by means of protective measures and maintenance systems was usually difficult for many steel structures, resulting in serious corrosion problems [12,13]. Generally, due to the difference of base material and environment medium, the metal corrosion under corrosion environment included two categories: uniform corrosion and local corrosion [14,15]. Various corrosion modes occurred and promoted each other. Therefore, corrosion was considered to be one of the most important factors resulting in the ageing of steel structures, which can lead to the uneven surface morphology, thickness reduction, fatigue cracks, brittle fracture, etc. [16].

Previous research on the corroded steel was focussed mainly on the hot-rolled steel and rebar, hence limited data are available for the mechanical properties of cold-formed steels with corrosion damage. Paik et al. [17] considered the influence of coatings and proposed a power function corrosion model with probability distribution parameters by

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Nomenclature

D_s	corrosion ratio
E_s	elastic modulus
f	design value of strength
f'	strength considering cold-formed
f_u	ultimate strength
f_y	yield strength
f_y^J	yield strength of the corner
f_y^W	yield strength of flat
f_{y0}^J	yield strength of non-corroded corner
f_{y0}^W	yield strength of non-corroded flat
F_{ya}	yield strength of total cross-section
F_{yc}	yield strength of corner
F_{yf}	yield strength of flat
L	length
n	number of edges
S_0	the cross-sectional area of non-corroded specimens
S_1	cross-sectional area of corner
S_2	cross-sectional area of flat
S_s	cross-sectional area of weak position
S_{min}	minimum cross-section area
t	thickness
δ	elongation
σ	stress
ε	strain
ε_u	ultimate strain
$\varepsilon_{\triangle}$	yield platform length
ε_y	yield strain
ξ	corrosion damage coefficient
η	forming mode coefficient
γ	ratio of ultimate and yield strength
θ	circumferential angle
C	ratio of bend area to total cross-sectional area

Fig. 1. Source of specimens.

Fig. 2. Comparison of corrosion status of specimens.

statistical analysis. Garbatov et al. [18] found that with corrosion damage increasing, significant degradation in strength and deformation of corroded steel plates can be observed. Burke et al. [19,20] investigated the effect of corrosion pits on the strength and ductility of the corroded steel, and the strength and ductility decreased significantly with the increase in the depth and density of corrosion pits. The corrosion pits also significantly affect fatigue life: The more and deeper the corrosion is, the more rapidly the fatigue life decreases [21,22]. In addition, it should be emphasized that the buckling strength of pitted members is smaller than or equal to the buckling strength of the members with uniform thickness loss in terms of average thickness loss [23]. Furthermore, experimental results showed that the bearing capacities and the stiffness of corroded connections decreased due to the losses of cross-section areas of both beams and columns, while the existence of severe pits in the welded zone accelerated the brittle fracture failure of corroded beam flanges [24]. In addition, a general procedure for the evaluation of the time variant capacity of thin-walled steel section is proposed and discussed in detail [25]. Generally, previous research showed that corrosion damage had a greater influence on the mechanical properties and structural performance of the steel. However, corrosion may exert different influences on different kinds of steel; thus, it is important to investigate the behaviour of cold-formed steel with corrosion damage.

The cold-formed steel exhibits a greater extent of strain hardening than carbon steel, which leads to significant changes in mechanical properties (increase in yield strength and decrease in ductility) of the steel material due to the cold-formed process. These changes in the mechanical properties depend mainly on the magnitude of the residual stresses and equivalent plastic strain induced by the cold-formed effect [26]. However, research showed that the corrosion resistance of cold-work hardening steel such as the corner parts of cold-formed steel was lower than the corrosion resistance of carbon steel, and the corrosion resistance decreased with the degree of deformation [27].