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Interfacial fracture morphologies of stainless steel clad plates after uniaxial tension

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Abstract. The interfacial fracture morphologies of stainless steel clad plates, dividing into stainless steel layer, diffusion layer and carbon steel layer, after uniaxial tension loading are investigated. It is found that the fractures occur randomly along the interface line between the stainless steel and diffusion layers, which could be induced by the stress concentration effect. The relatively high ductility of the carbon steel reduces the stress concentration to avoid the possible generation of the interfacial fracture in its layer. Furthermore, the bonding forces between the stainless steel and diffusion layers determine the distribution of the fractures. High bonding force could retain the interface without fracture, while the fractures would occur in the domains with low bonding force. This work deepens the failure mechanism of the stainless steel clad plates and is useful in the safety evaluation in their applications.

1. Introduction

Multifunctional clad materials and composites with good properties and various functions have developed in many industries. Among them, stainless steel clad plates are one of the most widely used products. Stainless steel clad plates not only have good weldability, ductility and thermal conductivity from carbon steel, but also hold high corrosion resistance, abrasion resistance and magnetic resistance from stainless steel. Various technologies are utilized to produce stainless steel clad plates, for instance, explosion welding, diffusion bonding and hot/cold-roll bonding [1-3].

In the past decade, the mechanical properties and failure behaviour of the stainless steel clad plates have been a focus of research. There exists a diffusion phenomenon of chemical elements around the interface line, resulting the generation of a diffusion layer [4-6]. Many researchers focus on the tension test of the clad plates to explain the interfacial fracture behaviour [7-9].

To our knowledge, few studies report the interfacial fracture morphologies of stainless steel clad plates after uniaxial tension loading. In order to understand these morphologies, the interfacial fracture of clad plate will be researched. This research will contribute to better discern the relationship between structure and performance.

2. Material and Methods

In this paper, the stainless steel clad plates under test are commercial hot-roll bonding products. The chemical compositions of the two materials are listed in table 1. The mechanical properties and bond quality satisfy the standard of ASTM A263-12 (Standard Specification for Stainless Chromium Steel-Clad Plate). The clad plates have a total thickness of 3 mm, in which the thicknesses of stainless steel and carbon steel are 1 mm and 2 mm, respectively.



The fractured surface of the clad plates and their layer sides along the thickness direction are both investigated. Correspondingly, two kinds of specimens are designed as shown in figure 1. Specimen A is applied to study the fractured surface after tension, and its geometrical sizes are given in figure 2. For observing the sides of the clad plates, Specimen B is adhered to four clamping pieces with epoxy adhesive, whose bond strength should be higher than 30MPa. And figure 3 illustrates the geometrical sizes of Specimen B and its adhesion scheme with carbon steel clamping pieces. Specimen A is tested on a universal testing machine, and Specimen B is tested on a SEM-SERVO In-situ fatigue testing machine. After the uniaxial tension, all specimens are observed by using scanning electron microscope (SEM).

Table 1. The chemical composition of stainless steel and carbon steel (wt%).

Elements	Cr	Ni	Mn	C	S	Si	P	Fe
SUS304	18.00	8.00	2.00	0.04	0.02	0.80	0.025	balance
Q235	0.00	0.00	1.00	0.17	0.04	0.30	0.045	balance

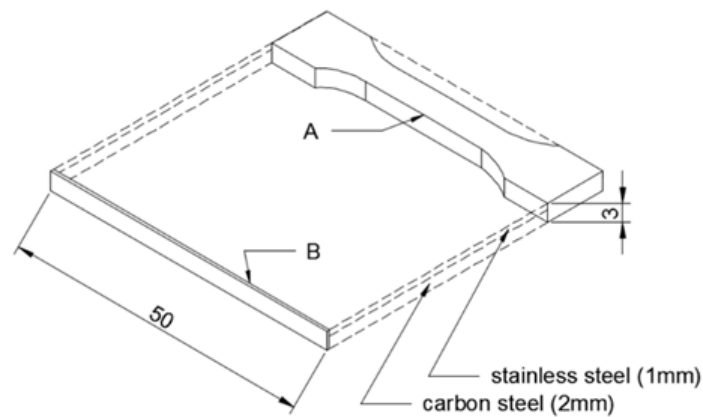


Figure 1. Two kinds of specimens for tension test: Specimen A and Specimen B.

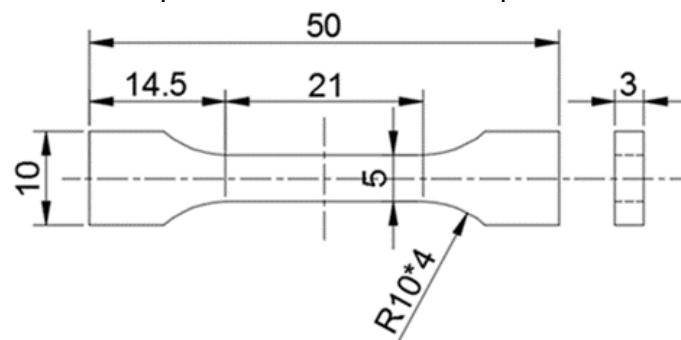


Figure 2. Geometrical sizes of Specimen A.

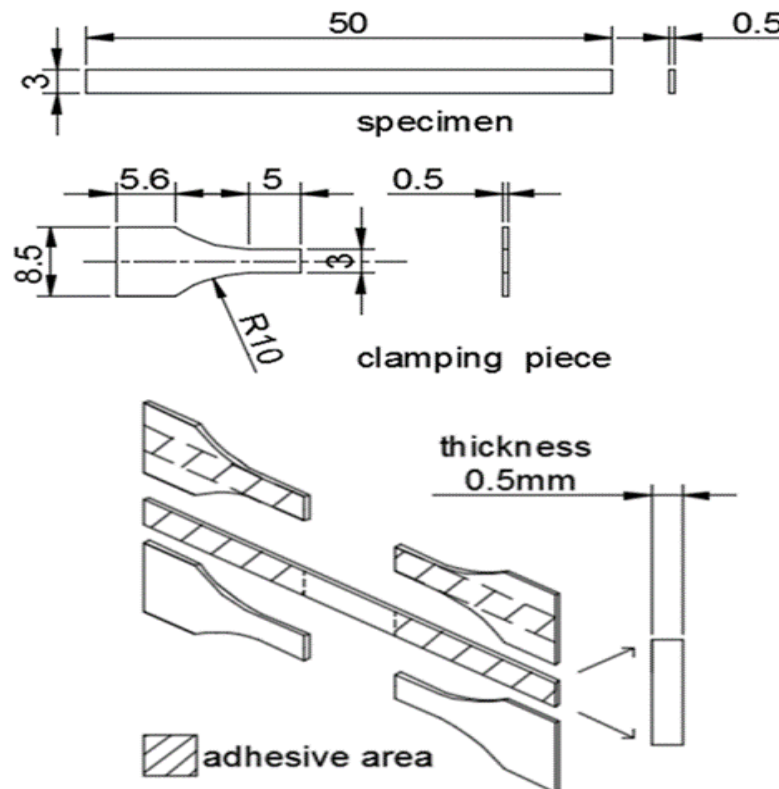


Figure 3. Geometrical sizes of Specimen B and its adhesion scheme for tension test.

3. Results and discussions

In the following analysis, the stainless steel clad plates are divided into three parts: stainless steel layer, diffusion layer and carbon steel layer. Due to the potential difficulty in the identification of the diffusion layer, its thickness is detected using energy-dispersive spectroscopy (EDS). The element distributions of the diffusion layer change monotonically along its thickness direction, while those are constant in stainless steel and carbon steel. Here the element distributions of Fe and Cr will be utilized to distinguish the diffusion layer between the other layers. And figure 4(a) shows the fractured surface of Specimen A after uniaxial tension, in which different morphologic characteristics are presented. As shown in figure 4(b), the diffusion layer has a thickness of about 20 μm , and good bonding between diffusion layer and stainless steel is exhibited. However, some fractures occur in the location of figure 4(c), while the stainless steel and diffusion layer still bond together. It is shown in figure 4(d) that there exists a large crack along the interface line between the stainless steel and diffusion layer. Interestingly, the interface between the carbon steel and diffusion layer always maintains good rather than generates fracture or crack.

The side observation of Specimen B after tension test is shown in figure 5(a). It is confirmed again that the fractures always occur along the interface line between stainless steel and diffusion layer as shown in figure 5(b). In other areas of the diffusion layer, including the middle part and the part near the carbon steel, no fractures exist. As shown in figure 5(c), micro-voids and micro-fractures are detected along the interface line between stainless steel and diffusion layer. But the sizes, the shapes and relative positions of these fractures have no existing rules to follow.

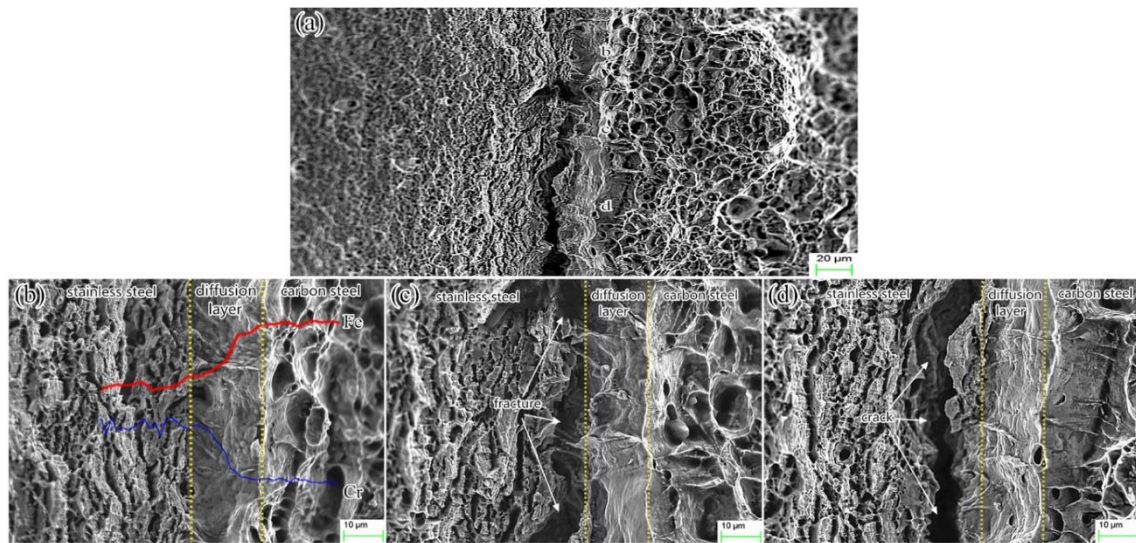


Figure 4. SEM micrograph of fractured surface after tension. (a) Macro-picture, and (b)–(d) micro-picture. (b) Distribution of Fe and Cr of diffusion layer via EDS.

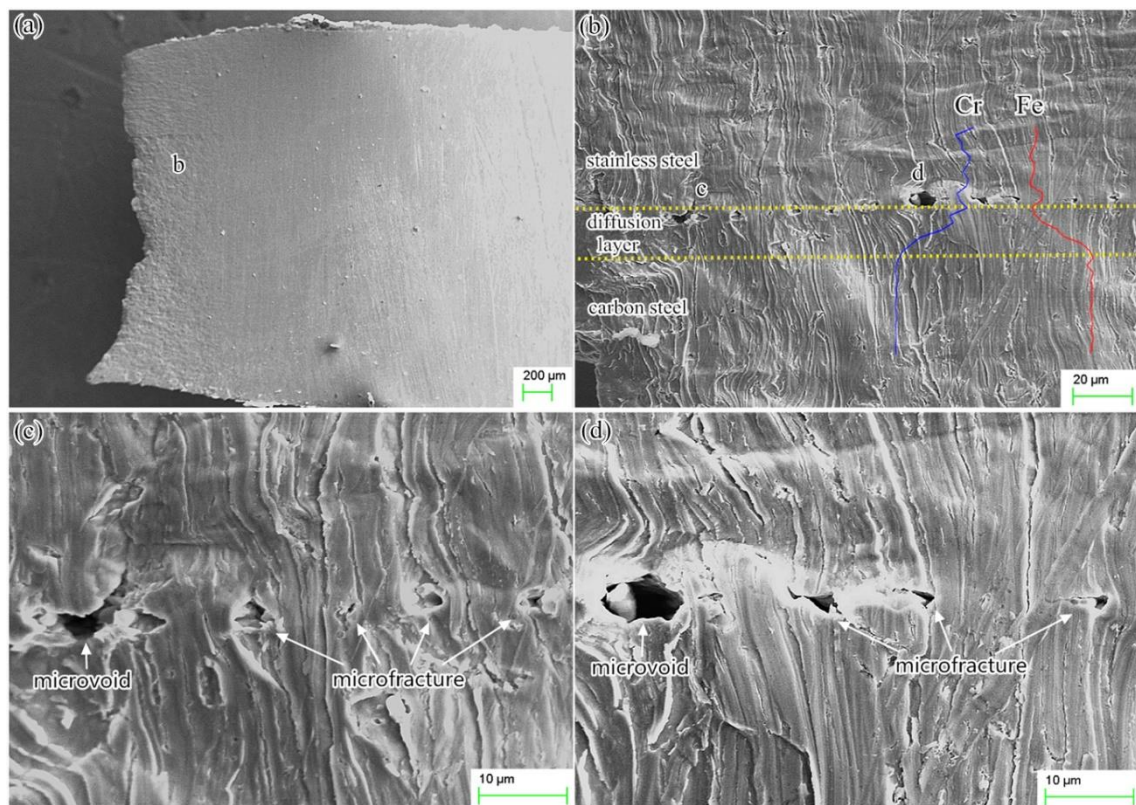


Figure 5. SEM micrograph of the side of the clad plate after tension. (a) A high magnification, (b) Macro-picture, and (c)–(d) micro-picture. (b) Distribution of Fe and Cr of diffusion layer via EDS.

The stainless steel, diffusion layer and carbon steel are bonded by bonding force. The bonds can be considered as rigid constraints along the interface line. During the tension loading, the deformation of the clad plates will cause stress concentration along the interface line and some fractures will occur when the stress is enough large. It is clear that the carbon steel is more malleable than stainless steel, which can reduce the effect of stress concentration better than stainless steel. Therefore, the fractures

arise more easily between stainless steel and diffusion layer, compared with those between carbon steel and diffusion layer. It should be mentioned that with the increase of tension to cause the rupture of the specimens, no fracture is observed between carbon steel and diffusion layer.

The random distribution of these fractures could correlate with the local bonding force. Theoretically, stainless steel is integrally and continuously bonded to carbon steel through the diffusion layer. However, the practical bonding forces are varied with the locations. After the uniaxial tension, high bonding force could retain the interface without fracture, while the fracture or voids would occur in the area with low bonding force. Thus, the interfacial fracture happens randomly between stainless steel and the diffusion layer.

4. Conclusions

In the stainless steel clad plate after uniaxial tension, the interfacial fracture occurs randomly along the interface line between the stainless steel and the diffusion layer. Stress concentration caused by the tension load induces the interfacial fracture. The relatively high malleability of carbon steel reduces the effect of stress concentration to avoid possible fractures. The fracture degree correlates with the degree of local bonding force. After tension, the area with large bonding force can bond well, and the area with poor bonding force can generate fracture.

Acknowledgments

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