DEVELOPMENT AND APPLICATION OF HIGH STRENGTH AND CORROSION RESISTANT ROLL-BONDED CLAD CHECKERED PLATE *

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Abstract

Checkered plate, which is also known as floor plate, has a raised pattern that provides excellent skid resistance for a wide range of applications, such as flooring, walkways, platforms, stair treads, covers, etc. As one of most common products, carbon steel checkered plate is used in low strength with a large thickness margin for corrosion and costs a lot in corrosion resistance treatment and maintenance. Although austenitic stainless steel checkered plate meets the requirements of general corrosion resistance, it is also hard to provide a highly comprehensive performance for its low yield strength, which mean higher thickness, higher weight, lower stability of structure. Combined the advantages of stainless steel and carbon structural steel, a roll-bonded clad checkered plate with high performance in skid resistance, high strength and corrosion resistant is developed. The metallography shows metallurgically bonded interfaces. Both external and internal bending at room temperature can be done successfully done without any cracks. The yield strength is also significantly improved. Therefore, roll-bonded clad checkered plate is superior in microstructure, strength, ductility and workability. An application case on a pulverized coal injection platform in an iron-making plant, is also introduced to show the way of processing and installation. After two years of installation on the platform, the product still keeps the original appearance. It implies that the developed plate could keep the facilities functions with much less or no maintenance and make them much safer.

Keywords: Clad steel product, roll-bonded, checked plate, microstructure, mechanical properties

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1 INTRODUCTION

With the advantages of surface appearance and non-slip, checkered plate is widely used in many fields, such as roads, stairs in industrial constructions, floors, running boards in special vehicles, etc. At present, there are two types of checkered steel plate, which are carbon steel checkered plate [1][2] and stainless steel checkered plate, but there are the following problems respectively. On one hand, long-term use of carbon steel checkered plate will lead to the emergence of safety risks due to corrosion, as shown in the example of Fig.1, the corrosion of the stairs made of carbon steel checkered plates is very serious over a period of time. Rust removing and coating/painting treatments for protecting cost enormous in investment and labour, and more serious situation is that many areas cannot be anti-corrosion treatment, such as dusty environment, not to mention the harm of using of anti-corrosion paint and other chemical substances to human health. Additionally, the strength of conventional carbon steel checkered plate is generally low, and the extra thickness for the corrosion usually results in a larger weight of the components. On the other hand, low yield strength of austenite stainless plate affects the stability of the structure, and welding difficulties between stainless steel checkered plate and carbon steel components are also needed to consider. Based on the above considerations, using high strength carbon steel as base material and austenite stainless steel as cladding material, a novel roll-bonded clad checkered plate product is developed and produced to achieve the properties combining both corrosion resistance and high yield strength.

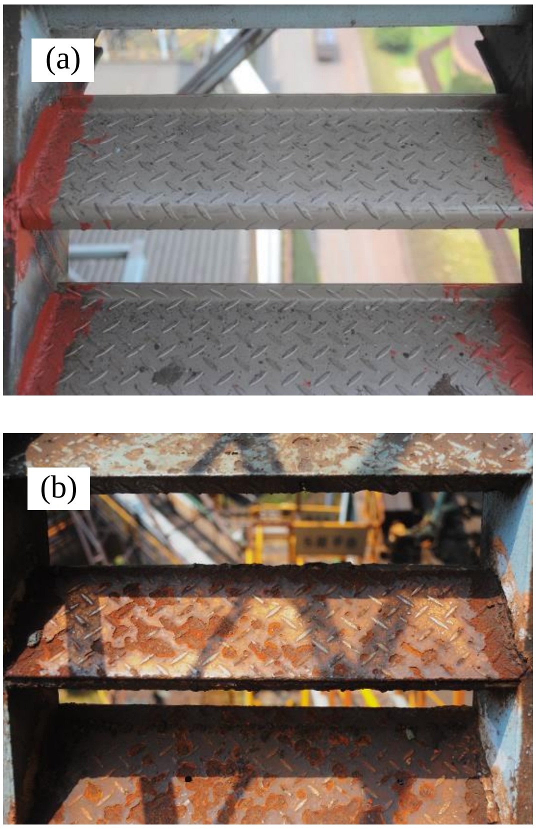
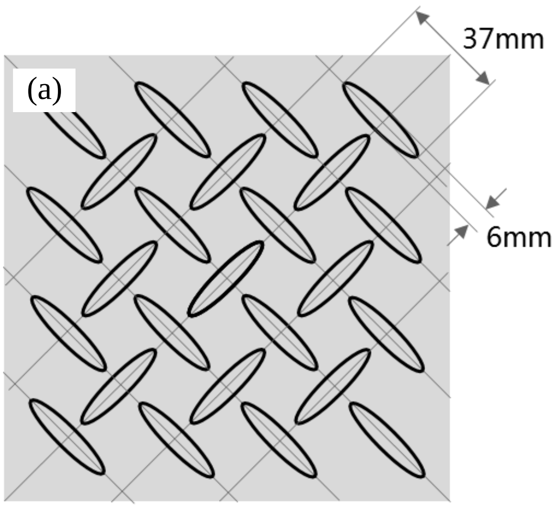


Figure 1. Comparison of the application of carbon steel checkered plate between the state of
(a) newly installed with anti-corrosion paint and that of (b) exposed to corrosive environment for a period time

2 EXPERIMENTAL DETAILS

2.1 Materials



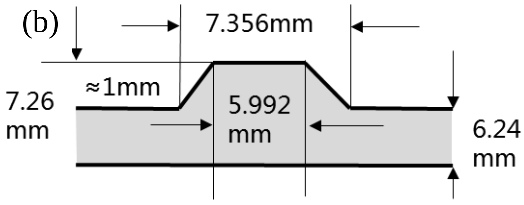


Figure 2. Appearance diagram of the roll-bonded clad checkered plate
(a) pattern shape; (b) pattern thickness

The roll-bonded clad checkered plate is designed into a sandwich structure. The upper and lower cladding layers are austenite stainless steel. Only the upper surface is rolled to bean-like pattern, and the lower surface keeps as flat. As shown in Fig.2, the size of the bean-like pattern is about 1mm in thickness, 37mm in length and 6mm in width, and the thickness of the flat portion below the pattern is 6.24mm. Fig.3 shows the roll-bonded clad checkered plate with a sandblasted and galvano chemically treated surface .

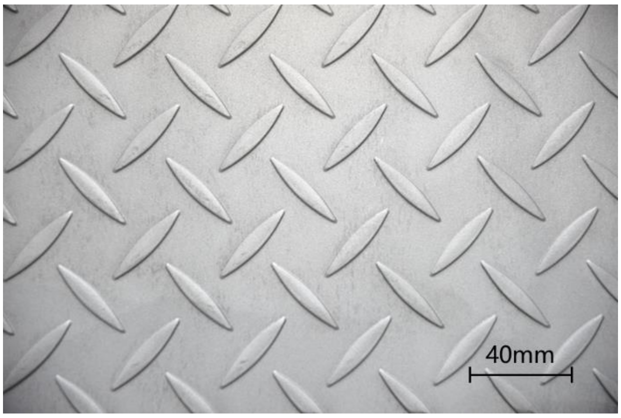


Figure 3. Photo of the roll-bonded clad checkered plate with a sandblasted and galvanochemically treated surface

2.2 Chemical Composition

The chemical composition of base carbon steel is shown in Table 1. The stainless steel grade for both upper and lower layers is SUS304L.

Table 1. Composition of base material

	C	Si	Mn	P	S	Cr	Nb	Ni
%	0.07	0.18	0.82	≤0.01	≤0.005	0.015	0.007	0.003

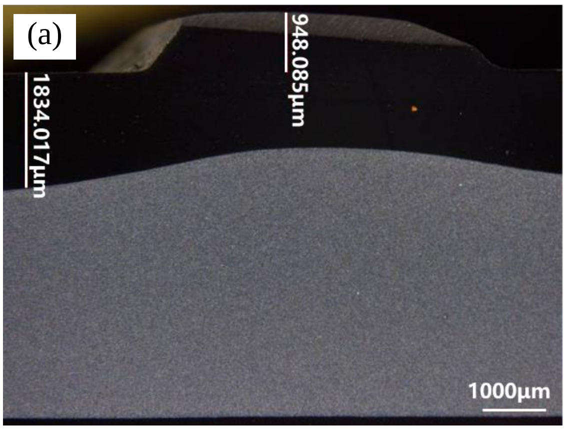
2.3 Macrostructure and microstructure observation and mechanical property tests

The cross section of specimens was mechanically polished to observe the macrostructure and microstructure by metallographic microscopy and scanning electron microscopy. The yield strength, tensile strength and elongation of JIS-5 specimens were tested by using Zwick / Roell Z330RED tensile test machine, and the results were compared with the conventional carbon steel checkered plate of the similar thickness. The bend tests were carried out at room temperature using a cold-bending test machine.

3 RESULTS AND DISCUSSION

3.1 Structural morphology

In low magnification, the overall morphology of cross-section of the plate is shown in Fig.4, the whole bean-like pattern has been completely filled by stainless steel of the cladding layer. The interface between cladding layer and base layer moves toward the upper layer in the area of pattern, and it is clear and continuous in Fig.4(a). It shows the continuity of metal flow direction of the base layer and the cladding layer during rolling process. Meantime, another interface between the lower cladding and the base layer is straight and continuous, as shown in Fig.4(b). The bonding quality of both interfaces looks very good.



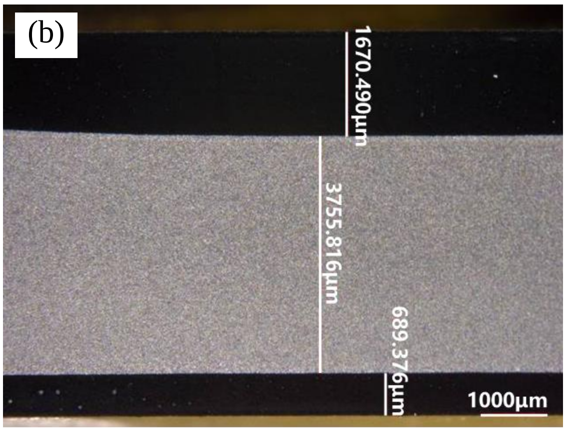


Figure 4. Macroscopic characteristics in the thickness direction
(a) the interface under the bean-like pattern;
(b) the interface of non-pattern area

Further increasing the magnification, as shown in Fig.5, it can be seen that a decarburization layer of about 20μm in the vicinity of the interface, and the interface is straight, and no defect is observed. Microstructure of base layer is ferrite and pearlite, which is refined and uniform. Average grain size of ferrite is less than 10μm.

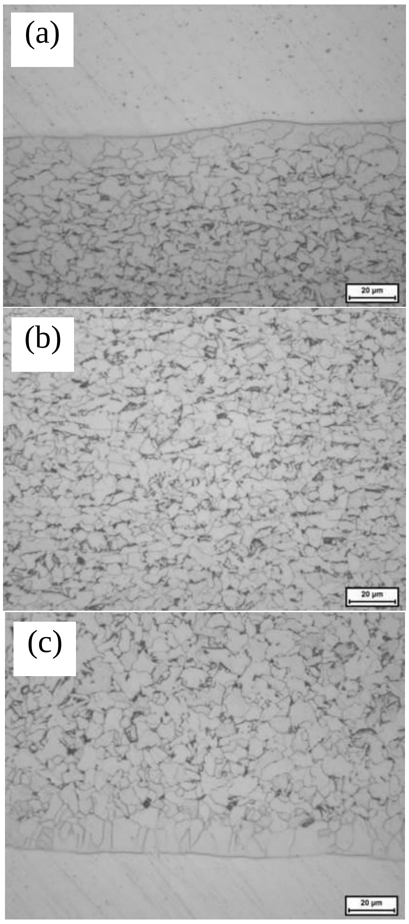
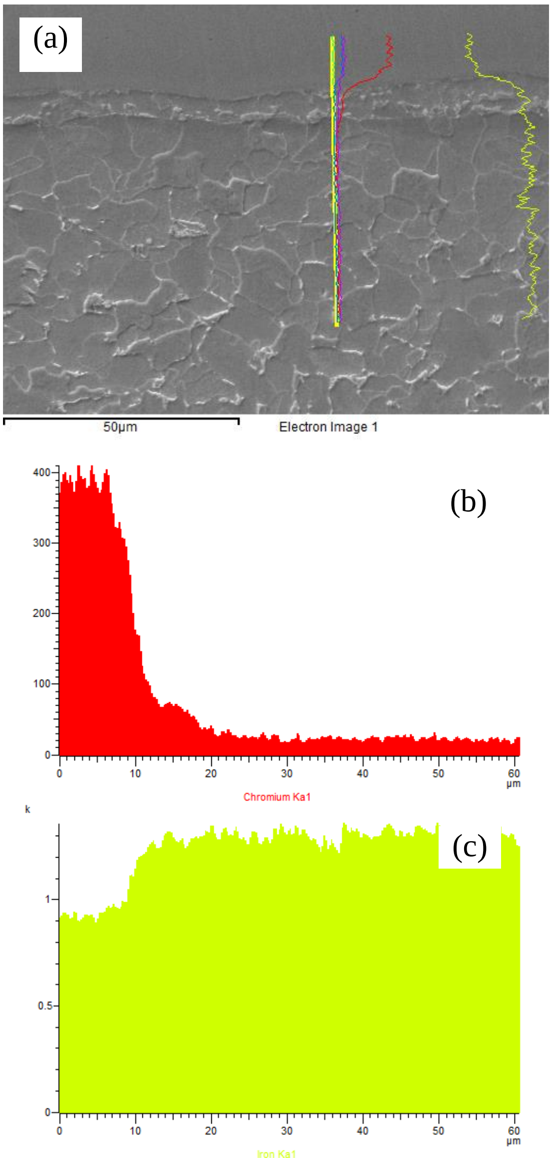


Figure 5. Microstructure of roll-bonded clad checkered plate
(a) microstructure of the interface between pattern layer and base layer;
(b) microstructure of the center of base layer;
(c) microstructure of the interface between lower cladding layer and base layer

In the interface area, the distribution of the main alloying elements such as Cr, Mn, Ni and Fe can be seen by line scan of SEM and the transition zone is about 10-12μm, as shown in Fig.6. The transition of the main alloying elements is smooth in the interface, indicating that metallurgical bonding between cladding layer and base layer has been reached.



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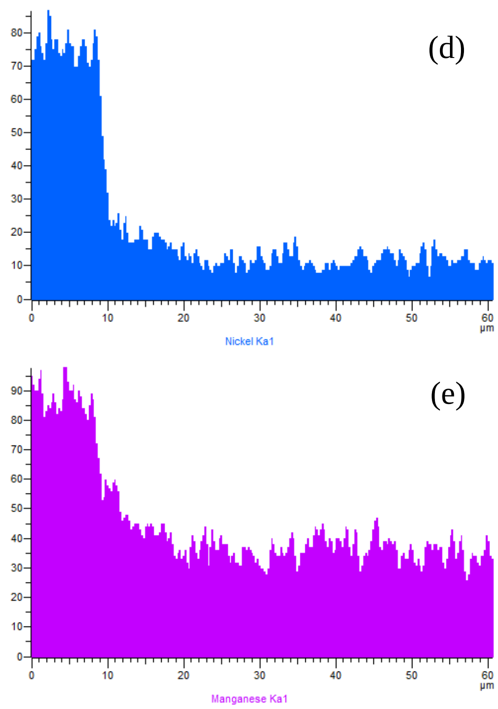

Figure 6. Element distribution across the bonding boundary
(a) line scanning of the interface; (b) Cr; (c) Fe; (d) Ni; (e) Mn

3.2 Structural morphology

The tensile curves of the full thickness specimen of roll-bonded clad checkered plates at room temperature are shown in Fig.7. It can be seen that specimen from different positions and different directions show the similar properties. As a comparison, the tensile curve of a typical carbon checkered plate with the same thickness is also shown in the figure and can be obviously seen that it is much lower than those of cladded plate. The average yield strength of roll-bonded clad checkered plate is about 484MPa, the average tensile strength is 627MPa, the uniform elongation and elongation to fracture are 27.5% and 37.3%, respectively. And the yield strength and tensile strength of the carbon steel checkered plate are 255MPa and 410MPa, uniform elongation and elongation to fracture are 16.1% and 30.9%, respectively. It shows that the mechanical properties of roll-bonded clad checkered plate is superior to that of carbon steel checkered plate. As shown in Fig.8, the fracture of the clad checkered plates after tensile test shows no significant difference compared with the carbon steel checkered plate, and the fracture is uniform without delamination, which also reflected the excellent bonding strength from the other side.

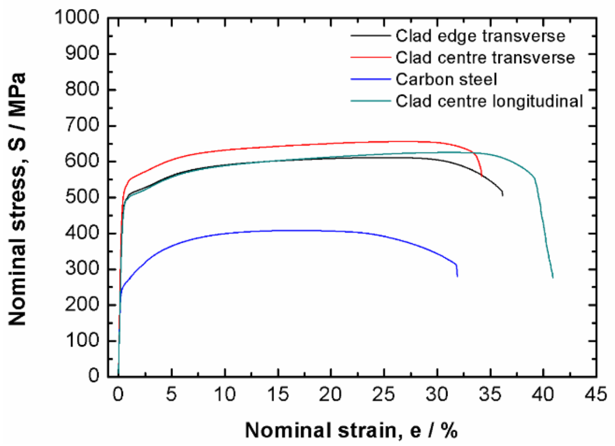

Figure 7. Tensile test curves of checkered plates

Table 2. Tensile properties of checkered plates

	YS (MPa)	TS (MPa)	Uniform Elonga-tion (%)	Elon-gation to fract-ure (%)
BHW01	484	627	27.5	37.3
Carbon steel checkered plate	255	410	16.1	30.9
SS 304 checkered plate	205	520		40.0

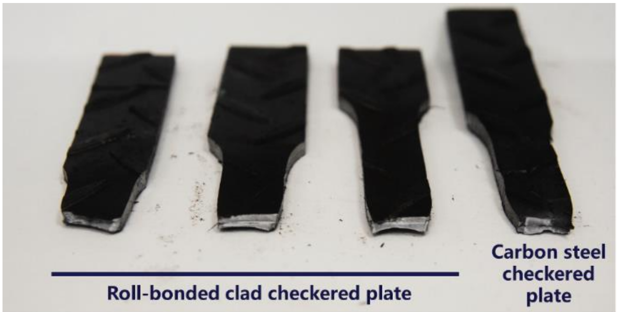

Figure 8. Fracture morphology of tensile test specimen

3.3 Cold bend test

The specimens with 20mm in width, 60mm in length have been tested by bend test machine at room temperature, including external bend (pattern layer is stretched) test and internal bend (pattern layer is compressed) test. The bending angle is 180° and the bending punch radius of the apparatus is less than the thickness of checkered plate.

Table 3. Results of cold bend tests

	Angle	Radius
BHW01	180°	0.7a

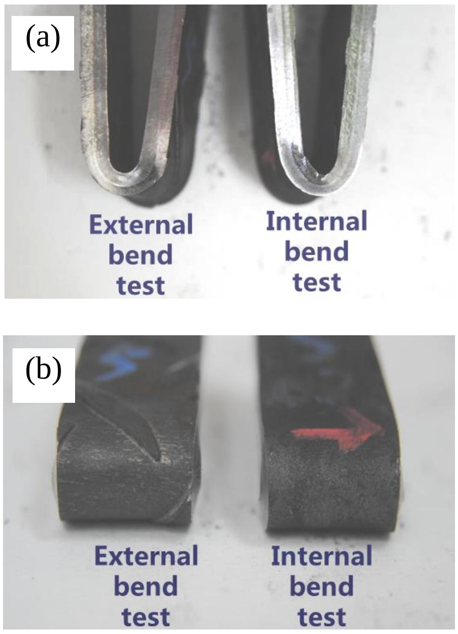

Figure 9. Photos of specimen after cold bend tests (a) the edge of the specimens;(b) the surface of the specimens

As shown in Fig.9, no crack is observed after tests, including the surface and the edge area. It shows high performance in bendability of the roll-bonded clad checkered plate.

4 APPLICATIONS

For the purposes of application and evaluation, the roll-bonded clad checkered plates were applied on a pulverized coal injection platform in an iron-making plant in August 2016, as shown in Fig.10. This platform has a large area, many floors, numerous equipments, complex environment, and huge workloads for anti-corrosion maintenance. The construction is shown in Figure 11, which including the cutting, laying and welding process, is basically the same as the case of using carbon steel checkered plates, in addition to eliminating the painting process for anti-corrosion purposes. At the same time, the carbon steel checkered plates are also laid on the same floor of the platform for comparison.

Figure 10. The pulverized coal injection platform

Figure 11. The construction of roll-bonded clad checkered plates

After continuous observation in two years, it can be seen that the surface of the roll-bonded clad checkered plate has not changed, and the carbon steel checkered plate has been obviously rusted.

Figure 12. Comparison of two kind of checkered plates after two years of use

5 CONCLUSIONS

After metallographic observation, analysis of mechanical properties, such as tensile tests and cold bend tests, and actual applications, the following conclusions can be drawn:

(1) The metallography shows cladded interfaces are very good, stainless steel filled the whole pattern, and the microstructure in different cladded layers are very uniform.

(2) The yield strength, tensile strength and elongation from tensile tests are significantly higher than the ones of conventional carbon steel checkered plates. In addition, fracture morphology also shows the excellent interfacial bonding strength.

(3) Both external and internal bend tests at room temperature were done successfully done at 180°, 0.7a without any cracks, which means excellent formability.

(4) Through the application of the pulverized coal injection platform in an iron-making plant, the construction of the roll-bonded checkered plate is basically the same as that of the painted carbon steel checkered plate, but it has better corrosion resistance. After two years, the carbon steel checkered plate laid in the same period has been obviously rusted, while the clad checkered plate remains in its original state.

In a word, superior performances in both corrosion resistant and high strength have been achieved on checkered plate by roll-bonding method to metallurgically clad austenitic stainless steel to high strength carbon steels. It is can be expected that the developed clad checker plate can be used to improve the safety and reliability of the facilities, buildings and constructions, and to reduce the maintenance work for painting and refinishing/refurnishing.

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