Preparation and performance of stainless steel clad carbon steel as grounding grid

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Abstract. To address the serious corrosion of carbon steel and large grounding resistance of stainless steel in substation grounding grid, in this work, 304 stainless steel (X5CrNi18-9, ISO 15510: 2014) pipe was clad over Q235 carbon steel rod (S235B, ISO 630-2: 2011) to produce stainless steel clad steel as grounding grid material through cold drawing and hot rolling method respectively. The results showed that stainless steel clad steel assembled by cold drawing had a stainless steel skin with uniform thickness, and the stainless steel skin was clad over the carbon steel rod in a physical combination way with contact spaces, and the bonding strength is merely 0.3kg/cm^2. Stainless steel clad steel assembled by hot rolling had a stainless steel skin with nonuniform thickness, the skin layer made of 6mm thick stainless steel has the minimum thickness larger than 1.24mm, and the bonding between stainless steel skin and carbon steel rod was found to be metallurgical combination. As regards grounding resistance, it was 1.36 times and 0.76 times that of Q235 carbon steel for assembled rod by cold drawing and hot rolling respectively. It can be concluded that the hot rolling type stainless steel clad steel is a desirable material meeting the discharge requirement of substation grounding grid well.
Keywords: ground mat; grounding resistance; stainless steel clad steel.

1 Introduction

Grounding grid is one of the key facilities to ensure the proper functioning of transformer substation [1], which plays the roles of thunder prevention, working grounding, discharging and voltage sharing etc. [2]. Galvanized steel has mainly been used as grounding grid material in our country [3], however, it is prone to severe corrosion with soil [4], thus leading to decrease of its thermal stability, shrink of cross-sectional area and increase of grounding resistance. Sometimes fracture is discovered especially for the steel operated under high voltage levels and extreme corrosion environment [5]. Stainless steel has better corrosion resistance, however, its shortage of lower electrical conductivity than carbon steel may decrease the discharge capability of grounding grid, which makes it difficult to realize direct application. Aiming at addressing the above practical situation, Q235 carbon steel as matrix material with 304 stainless steel clad over its outside surface was fabricated to produce material of stainless steel clad steel and the effects of fabrication methods including cold drawing and hot rolling on grounding resistance of the material were discussed, which we hope can provide a new type of anticorrosion material for grounding grid.

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2 Experimental materials and methods

The experimental materials used in this work were Q235 carbon steel and 304 stainless steel. Their chemical compositions are shown in table 1.

Table 1. Chemical compositions of the grounding grid materials used in this work.

Elements	C	Si	Mn	P	S	Ni	Cr	Ti	N	Fe
Q235	0.22	<0.05	0.48	0.012	0.022	-	-	-	-	Balance
304	0.039	0.44	1.210	0.018	0.002	8.09	18.23	0.042	0.039	Balance

Fabrication through cold drawing method: In order to avoid corrosion of stainless steel, the stainless steel serving as surface skin layer is required to thicker than 0.3mm, and to keep proper discharge of grounding grid, the sectional area at least more than 300mm^2 is needed according to design requirement for grounding grid. For performing process of stainless steel clad steel, Q235 steel rod (22mm in diameter) and 304 stainless steel pipe (0.6mm thick and 22mm in inner diameter) were adopted as raw materials. The selected stainless steel pipe was pre-clad over the carbon steel rod, which was then drawn through a mould (21.8mm in diameter) to assemble a tightly clad carbon steel rod by stainless steel. Before drawing, the carbon steel rod was treated by grinding wheel to remove rust and to form a rough surface. The rust removed steel rod with a diameter around 21.9mm can facilitate the pre-clad process of the 304 stainless steel pipe by press machine, and the well clad rod was then cold drawn with a mould. The stainless steel after drawing is kept around 0.3mm thick due to its large original thickness and good ductility.

Fabrication through hot rolling method: the 304 stainless steel with thickness of 6mm was pre-clad over the outside surface of carbon steel rod with diameter of 100mm and then heated at 1200°C, followed by 6 processes of hot rolling the stainless steel clad steel rod was assembled. This method can obtain a Q235 steel rod about 22mm in diameter clad by a 304 stainless steel skin no less than 0.3mm thick.

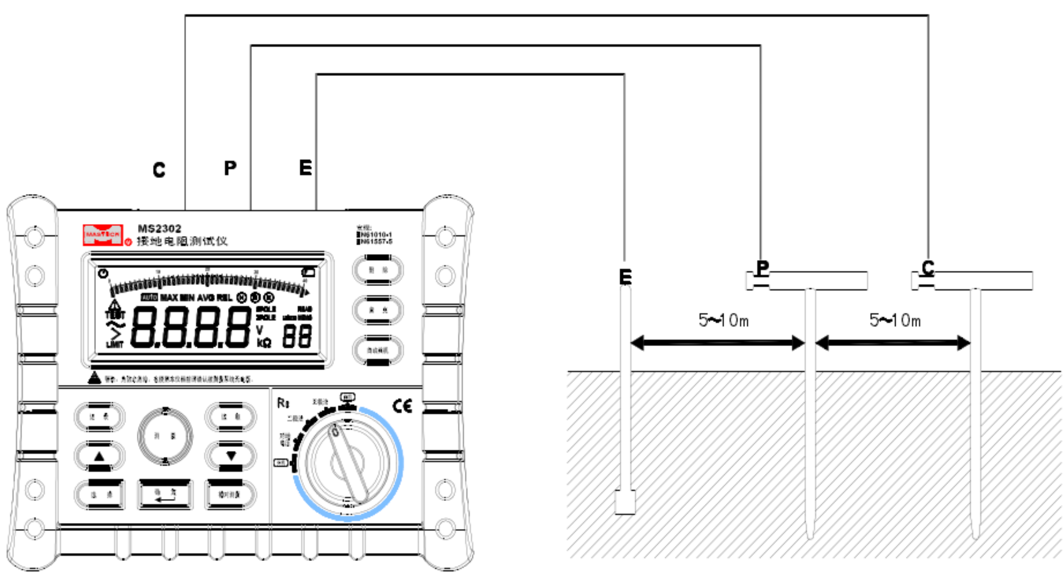

Figure 1. Schematic diagram of grounding resistance tester and its connection way

Grounding resistance was measured by three electrodes method [6], through arranging three grounding electrodes along a straight line in the field, the grounding resistance of corresponding material can be obtained from the detector display. The detailed operation method is shown in Fig. 1. It is indicated that point C is set as current electrode, point P is set as voltage electrode and point E is connected with the material being tested. Based on gradient of 5cm, the grounding resistance of galvanized steel and stainless steel clad steel buried in 10~55cm deep underground soil of an 110kV transformer substation were tested respectively. Multiple measurements were performed to take an average.

3 Results and discussion

The rod assembled by cold drawing is proved to be physical combination between the stainless steel pipe and carbon steel rod, which has poor bonding strength. The tensile experiment shows that the bonding strength is merely 0.3kg/cm^2. Fig. 2 gives the sectional surface image of the stainless steel clad steel assembled by cold drawing. It reveals that the stainless steel skin is 0.3mm thick and the Q235 steel rod is 21.6mm in diameter.

Figure 2. Sectional surface image of the stainless steel clad steel assembled by cold drawing

It also can be observed from Fig.2 that there are some spaces between the stainless steel skin and Q235 steel rod. In order to prove the existence of these spaces, 50cm long assembled rod by cold drawing was randomly picked out and of which the inner Q235 steel rod on the top end was removed by turning, afterwards, the remaining hole was filled with water for leakage examination. Finally, the water quickly infiltrated into the spaces and refilling water caused further leaks from the opposite end of the assembled steel rod.

To address the issue of poor bonding strength with cold drawing, a new type of processing technology hot rolling was used. The 6mm thick 304 stainless steel was pre-clad over the outside surface of carbon steel rod with diameter of 100mm and then heated at 1200°C, followed by 6 processes of hot rolling the stainless steel clad steel rod was finally assembled. During this fabrication, it was found that cracks tended to appear at the ends of the stainless steel skin layer, and the more rolling processes, the larger cracks. If any end of the stainless steel cracks, the assembled rod could not be plunged into the rolling machine and eventually making it harder to be processed. To avoid the cracks at the end of stainless steel skin, stainless steel welding rod was adopted to carry out sealing to both ends of the pre-clad rod, however, both ends of the stainless steel skin still cracked by rolling, resulting in a worse rolling product. A further analysis reveals the main reason for the formation of cracks, it is found that there are air gaps in the spaces of pre-clad rod (between carbon steel 100mm in diameter and 6mm thick stainless steel skin), which is physically squeezed out during hot rolling. When the both ends of the pre-clad rod are sealed, the heated air would break through the stainless steel skin to develop cracks to the assembled rod easily. Therefore, the carbon steel rod was designed to be 10mm shorter than its steel stainless skin for hot rolling process, and the ends were vacuumed before sealing. The improved hot rolling method is as follows: 304 stainless steel (102mm in inner diameter and 1010mm long) was pre-clad over the outside surface of the original carbon steel rod (100 mm in diameter and 1000mm long), then both ends were sealed by stainless steel plate after vacuumizing, the sealed rod were heated at 1200°C in an oven, and followed by 6 processes of hot rolling to obtain the target product. This improved method also can ensure an assembled rod that is 22mm in diameter clad by a 0.6~1.0mm thick stainless steel skin. The detailed process route is shown in Fig.3. Finally, stainless steel clad steel material can be assembled in a continuous manner through the above improvement and Fig. 4 gives the sectional surface image of the finished stainless steel clad steel rod by hot rolling.

Figure 3. Process route map of hot rolling

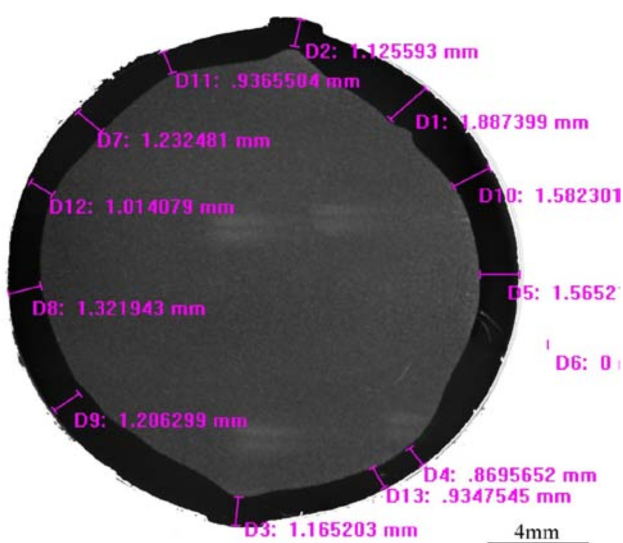

Figure 4. Sectional surface image of the stainless steel clad steel assembled by hot rolling

As shown in Fig. 4, the combination between the stainless steel skin and Q235 carbon steel rod assembled by hot rolling is metallurgical bonding, moreover, the average thickness of the stainless steel skin is 1.24mm, the maximum thickness is 1.88mm and the minimum is 0.86mm.

Grounding resistance refers to resistance that impedes the current passes through grounding electrode into underground and shunts to the surrounding. Also, it is the main parameter reflecting the electrical performance of grounding grid. Especially in the cases of short-circuit fault and thunder strike, the grounding resistance increases a lot to bring about insufficient discharge, which easily causes damages to electrical equipment or even pose threats to personal safety. Therefore, the stainless steel clad steel as grounding grid material is a feasible solution because its resistance is lower than that of the same-sized iron grounding grid.

Fig. 5 reveals grounding resistance of materials buried in 10~55cm deep underground soil of an 110kV transformer substation measured by three electrodes method. It is shown that grounding resistance of the grounding grid material assembled by cold drawing is larger while the assembled material by hot rolling is smaller in comparison to the same-sized Q235 steel.

Generally, grounding resistance of grounding system is composed of three parts including resistance of grounding material, contact resistance between grounding material and its surface-touched soil, thirdly, discharge resistance decided by surrounding soil of the grounding material. When iron grounding grid is used, iron is corroded to form iron oxides which posses larger resistance and easily adheres to the iron surface, as a result, the contact resistance between iron and its surface-touched soil increases accordingly [7]. By comparison, stainless steel is anti-corrosive and harder to form rust layer on the surface, thus, it is easy to obtain smaller grounding resistance for stainless steel clad steel as grounding grid in the same type of soil. However, there are some spaces between the outer stainless steel skin and inner Q235 steel rod for the assembled rod by cold drawing, and these spaces tend to increase the grounding resistance due to poor contact.

It also can be seen from Fig.5 that, at the buried depth above 30cm, 0.76 times and 1.36 times for the assembled rod by hot rolling and cold drawing are revealed respectively when compared to the grounding resistance of Q235 steel, indicating that the hot rolling type stainless steel clad steel is a desirable material meeting the operation requirement of substation grounding grid well.

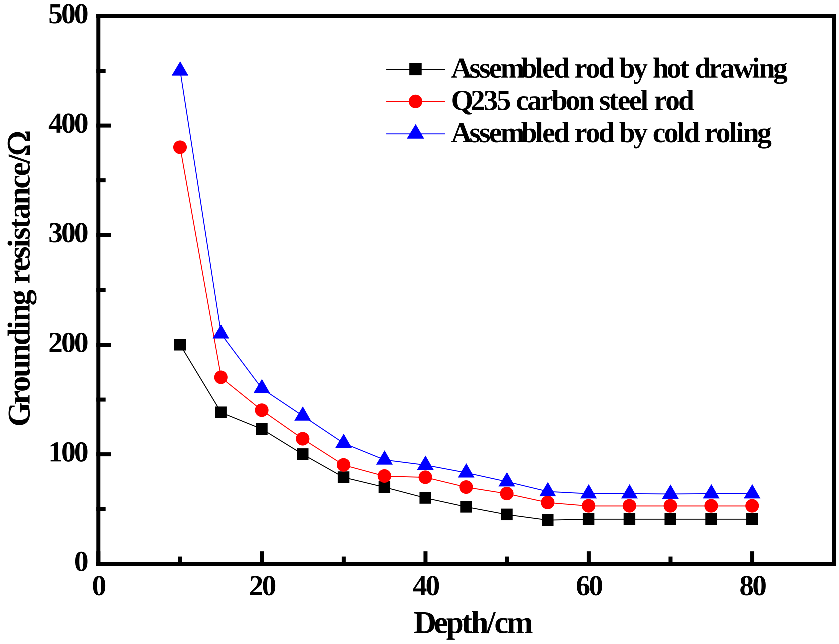

Figure 5. Grounding resistance measured under different depths

4 Conclusions

Stainless steel clad steel assembled by cold drawing had a stainless steel skin with uniform thickness, and the stainless steel skin was clad over the carbon steel rod in a physical combination way with contact spaces, and the bonding strength is merely 0.3kg/cm^2. Stainless steel clad steel assembled by hot rolling had a stainless steel skin with nonuniform thickness, the skin layer made of 6mm thick stainless steel has the minimum thickness larger than 1.24mm, and the bonding between stainless steel skin and carbon steel rod was found to be metallurgical combination. As regards grounding resistance, it was 1.36 times and 0.76 times that of Q235 carbon steel for assembled rod by cold drawing and hot rolling respectively. It can be concluded that the hot rolling type stainless steel clad steel is a desirable material meeting the discharge requirement of substation grounding grid well.

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