STUDY ON NON-ELECTRIC WELDING AND ITS APPLICATION IN MAINTENANCE

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Abstract: Non-electric welding is a novel efficient technique for emergency maintenance, which utilizes the heat released by self-propagating combustion to join metals without needing any power supply or gas sources. Non-electric welding material, named non-electric welding pen, was prepared by utilizing highly-exothermic thermite (CuO+Al) with other additive powders. The welding pen had a controllable combustion velocity and possessed high combustion temperature. The effects of reactant particle size and the uniformity of mixing on the combustion characteristic of the welding pen were investigated. The results showed that the particle size of reactant powder had a significant effect on combustion velocity. With increasing the particle size of reactant powder, the combustion velocity decreased obviously. Moreover, uniformity of mixing and particle size were shown to be main factors influencing heat produced in single time, and accordingly affected the combustion temperature. Welding experiments were performed with 45 steel as the weld object, and it showed that the weld metal jointed the weld object in a metallurgic connection with the tensile strength above 280 MPa, which proved non-electric welding a fusion welding technique. The practical weld repair of some equipments was carried out and the performance was good, meeting the operation requirement.

Keywords: Non-electric welding; maintenance; self-propagating high-temperature synthesis; combustion velocity

Due to the increasing of operation intensity of various field equipments, development of efficient emergency maintenance technologies is of great importance today. Welding is considered one of the primary emergency maintenance technologies for equipments, and the commonly used are electric welding and gas welding. However, the application of traditional electric or gas welding machine in emergency maintenance is greatly restricted in that the special geographic surroundings and the hard working condition make it difficult to provide high-power supply or gas storage. Some other relatively portable welding machines are also restricted in emergency maintenance because of the requirement of corresponding gas source. For the field damage of equipments, non-electric welding is an efficient in situ repair technology.

1 Non-electric welding and its characteristic

Non-electric welding is an innovative evolution from Self-propagating High-temperature Synthesis(SHS) welding. SHS welding utilizes the SHS reaction heat to join materials, and finds wide applications in joining refractory metals, ceramics and intermetallic compounds[2-5]. However, SHS welding typically requires a set of vacuum and high-pressure reaction furnace and heating apparatus, resulting in an operation inconvenience. Non-electric welding is a novel welding method, in which advanced welding thermite is formed into a manual pen-shaped welding rod, named welding pen, ignited just by a match, then the heat released by highly exothermic thermite is used as energy source to melt and join materials. Non-electric welding has the advantages of high temperature, rapidity and in situ welding, therefore shows excellent application potential in such fields as maintenance and remanufacturing. Compared with other welding methods, non-electric welding possesses such characteristics as:

(1) Non-electric welding utilizes the heat released by self exothermic reaction as welding energy, gaining high temperature(up to 3000～4000℃ as in some cases), therefore is of energy- saving.
(2) The welding pen is portable and ignited just by a match, needing not any power supply and gas source, easily operated, and so suitable for rapid emergency welding repair, and is of high efficiency.
(3) Non-electric welding belongs to fusion welding,

insusceptible to the object surface. The joint obtained by non-electric welding has a tensile strength of 200～300MPa, a bend strength of 300～700MPa, an impact toughness of 16～55 J/cm^2, a hardness of 120～180HRB, and an anticorrosion performance better than 45 steel, hence effectively meeting the emergency repair for equipments.

(4) Non-electric welding is able to join homogeneous or heterogeneous metals and can be widely applied in the repair of various equipments.

2 Investigation on non-electric welding

The preparation of welding pen is the key of non-electric welding technology, which involves the subjects of chemistry, physics, materials science, metallurgy and combustion. On one hand, the combustion of welding pen must be able to release sufficient heat so as to melt the metals, therefore the determination of exothermic reactants is essential to obtain high combustion temperature; moreover, the manual operation requires a not too intense reaction, namely, welding pen should have a controllable combustion velocity. On the other hand, the combustion of welding pen is supposed to yield some molten metal to form the joint. So it is necessary to focus investigations on that of the effects of various factors on welding pen combustion, and on that of the determination of the properties of the welded joint.

2.1 The frame of non-electric welding pen

The welding pen is composed of paper pipe, reactant compact, plug and starter with a fuze, as illustrated in Fig.1. The reactant compact is fabricated by pressing powder mixture of thermite, slag-generating agents and other additives into the paper pipe. The plug is set in one

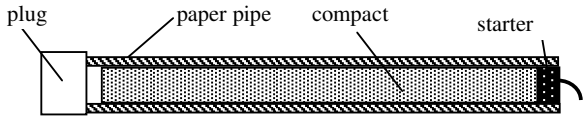

Fig.1 Schematic diagram of the non-electric welding pen

end of the pipe to seal the compact and serve as a grip when welding. The starter with a fuze is set in another end of the pipe to ignite the compact. The welding pen typically has an outer diameter of φ16 mm～φ25 mm, a length of 150 mm～600 mm. When ignited by a match, the starter starts the combustion of the compact and a great heat is released which melts part of the objects and the resultant metals from the reaction. Then a metallurgic joining is formed between the objects and the resultant metals, while other resultant nonmetallic covers the welding line as slags.

2.2 Effects on the combustion characteristic of non-electric welding pen

Many parameters affect the combustion of the welding pen, including reactant composition, uniformity of mixing, particle size and distribution, filling density, gas and atmosphere, etc. Moreover, the combustion temperature and combustion velocity are mutually related to each other. High combustion temperature leads to intense reaction, hence increasing the combustion velocity, while low combustion velocity results in less heat released, accordingly decreasing the combustion temperature.

Non-electric welding pen was prepared by utilizing highly-exothermic thermite(CuO+Al) with other additive powders, and effects of particle size and uniformity of mixing on the combustion characteristic was studied. Raw aluminum reactant used were three kinds of powders of different particle sizes with purity higher than 99.1 wt.%. And the average particle sizes of aluminum powders were determined to be 74um, 48um and 19um respectively using Malvern Microplus typed laser sizer, as demonstrated in Fig.2.

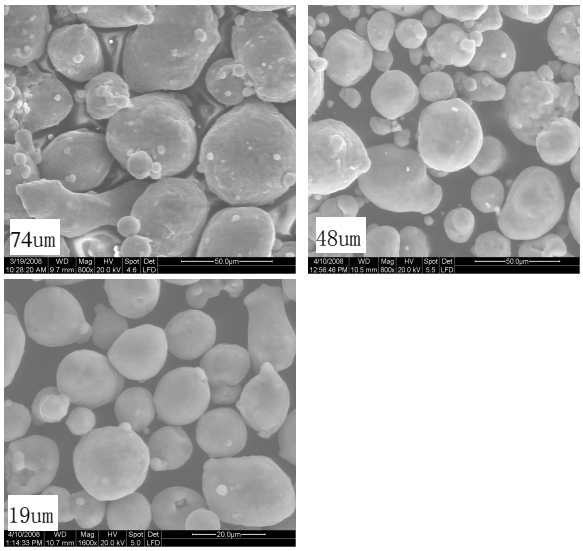

Fig.2 SEM micrographs of aluminum powders of different particle sizes

Tab.1 presents specifications of welding pens prepared with aluminum powders of different diameters and results of combustion velocity, where combustion velocity refers to the speed at which the combustion propagates from the beginning to the end of the specimen. As can be seen, with the decrease of particle size of

aluminum powder, the combustion velocity of the welding pen obviously increased. Decrease of average diameter of aluminum powder from 74um down to 19um resulted in the increase of combustion velocity from 5.9mm/s up to 10.8mm/s, which proves the combustion velocity almost doubled.

Average particle size (um)	Welding pen diameter (mm)	Welding pen length (mm)	Combustion time (s)	Combustion velocity ($mm \cdot s^{-1}$)
74	18	400	67	5.9
48	18	390	58	6.7
19	18	390	36	10.8

Tab.1: Summary of welding pens and combustion velocity

There is a direct close relation between the combustion velocity of the welding pen and the reactive rate of reactant powders. And the reactive rate is directly related to the contact area between the reactants, therefore it is dependent on the particle size of the reactants. Decreasing the particle size of the aluminum resulted in the increase of the specific surface area, caused the acceleration of the reactive rate accordingly, and led to the increase of the combustion velocity eventually.

Fig.3 demonstrates the maximal combustion temperature of welding pens prepared with aluminum powders of different sizes. It is clear that in the case of aluminum powder of 19um, the combustion temperature of welding

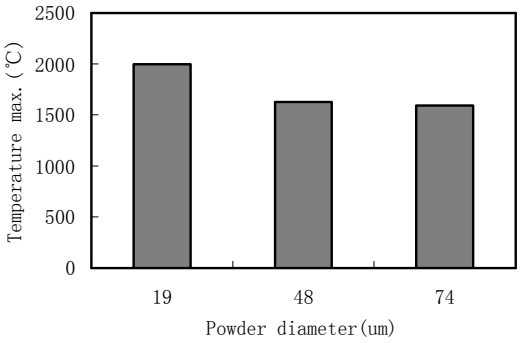

Fig.3 Maximum combustion temperature of welding pen

pen was the highest, reaching 1995℃, which was remarkably higher than the other two. Yet, the combustion temperature was 1618℃ and 1592℃ respectively in cases of aluminum powder of 48um and of 74um, which was approximately equal to each other. It is well apprehended that it is the reactive heat released in a unit time that contributes to the combustion temperature. The decrease in particle size led to the speeding up of the welding pen combustion, which released much more heat, and hence resulted in the increasing of combustion temperature. On the other hand, the experimental result for combustion temperature may be attributed to the mixing uniformity of reactant mixture. When the reactant mixture has a high degree of mixing uniformity, it will combust completely, releasing much heat, hence causing a high combustion temperature; while the reactant mixture is not mixed even, the combustion will not proceed fully and releases less heat, furthermore, the residual components unreacted will absorb some released heat, therefore the combustion temperature will be low.

2.3 Microstructure and property of non-electric welded joint

Welding experiments were performed with 45 steel plate as the weld object. The 45 steel plate was of a dimension 100mm long, 55mm wide and 4mm thick, and the joint was of straight butt downhand weld. Testing was carried out on the joint.

Heat released by the welding pen combustion fused part of the 45 steel plate with the resultant metals of reaction, which then produced a metallurgic joining as the temperature was down. Fig.4 gives the microstructure of the weld line. The texture of the weld line was not even.

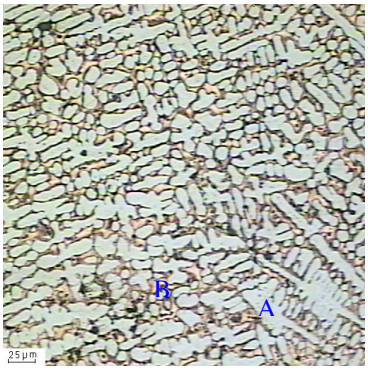

Fig.4 Morphology of weld line

It may be attributed to the fact that during the process of crystallizing the chemical components had not enough time to diffuse because of the rapidity of cooling, causing the uneven distribution of alloy elements. It can also be seen from Fig.4 that the weld line contained two phases of A and B which were determined by XRD analysis to be copper-nickel and copper-iron-nickel solid solutions respectively, as shown in Fig.5. And EDX patterns in Fig.6 also prove that result.

Fig.7 illustrates the comparison of tensile strengths

between the non-electric welded joint and 45 steel and

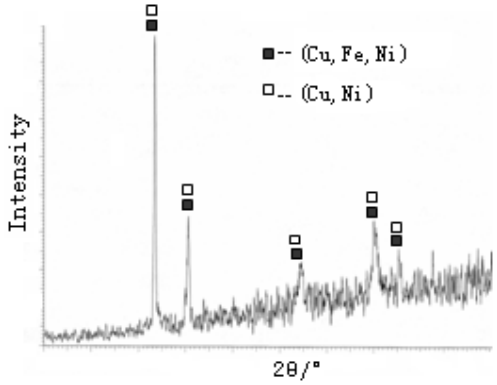

Fig.5 XRD pattern of weld line

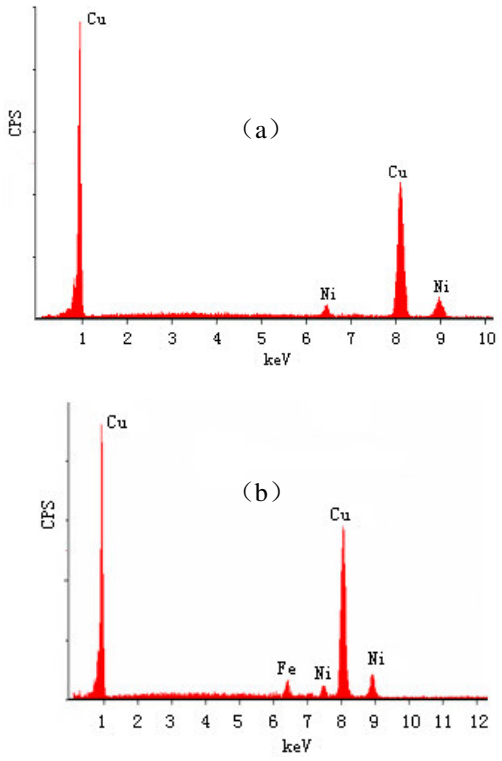

Fig.4 EDX patterns of A phase(a) and B phase (b) of weld line

A3 steel. The tensile strength of the joint was above 283MPa, about equal to that of A3 steel but lower than

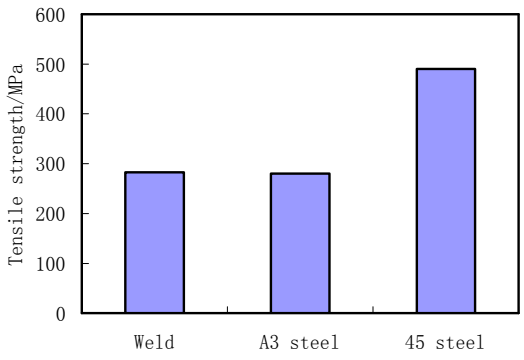

Fig.7 Tensile strength of welded joint

that of 45 steel, which is high enough to meet the requirement of emergency maintenance for field equipments. This can be explained by the fact that non-electric welding belongs to chemical thermal fusion welding and produces a metallurgic connection of high strength between the weld object and the weld metals.

3 Application of non-electric welding

Non-electric welding has a wide application in rapid repair for the fracture, damage, crack and hole of mechanical parts as well as for the sweating, dripping and leaking of pipelines and trunks. And it can also be applied in the emergency construction and repair in the case of earthquake and mine accidents, etc.

Two series of non-electric welding pens have already been successfully developed among which one is able to weld steel plates of 6～10mm thick, and the other can be used to join steel plates not thicker than 5mm. And practical welding was performed on some equipments, and the repair performance was rather satisfying, meeting the operation requirements.

4 Conclusions

(1) Non-electric welding is a chemical thermal fusion welding method, which uses the heat released by highly-exothermic thermite to join metal objects with the resultant metals as filler. And the filler jointed the weld objects in a metallurgic connection with the tensile strength above 280 MPa,

(2) The particle size of reactant powder has a significant effect on combustion velocity of welding pen. With increasing the particle size of reactant powder, the combustion velocity decreases obviously. Combustion temperature altering of welding pen is attributed to mixing uniformity and particle size.

(3) Non-electric welding is of convenient operation and of satisfying repair performance without needing any power supply or equipments, and finds a wide application prospect in emergency maintenance.

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