Rare Metal Materials and Engineering
Volume 54, Issue 11, November 2025
Available online at www.rmme.ac.cn

Science Press

Cite this article as: Cheng Yafang, Dong Bowen, Dong Xian, et al. Research Progress and Application of Flux-Coated Brazing and Soldering Materials[J]. Rare Metal Materials and Engineering, 2025, 54(11): 2802-2808. DOI: https://doi.org/10.12442/j.issn.1002-185X.20240569.

REVIEW

Research Progress and Application of Flux-Coated Brazing and Soldering Materials

Cheng Yafang[1,2], **Dong Bowen**[2], **Dong Xian**[2], **Zhong Sujuan**[2], **Long Weimin**[2]

[1] School of Materials Science and Engineering, Zhengzhou University, Zhengzhou 450001, China; [2] State Key Laboratory of High Performance & Advanced Welding Materials, China Academy of Machinery Zhengzhou Research Institute of Mechanical Engineering Co., Ltd, Zhengzhou 450001, China

Abstract: Flux-coated brazing and soldering material is a type of material-saving and emission-reducing composite material in recent years, which is the representative product of the development of brazing and soldering technology, which is highly concerned by welding researchers worldwide. This work mainly reviewed the research reports on the design, preparation technology, and application of flux-coated brazing and soldering materials, put forward the shortcomings of current research, and proposed the future research directions mainly focusing on the standards, the synergistic reaction mechanism between flux and metals, the alloying, and the morphology of flux-coated brazing and soldering materials in order to provide reference information and theoretical guidance for related research and technological development in the field of welding.

Key words: flux-coated brazing and soldering materials; structural design; preparation technology; alloying; standard

1 Introduction

The policy document *Made in China 2025* explicitly requires comprehensive implementation of green manufacturing, increasing the research and development of advanced energy-saving and environmentally friendly technologies, processes, and equipment, and accelerating the green transformation and upgrading of the manufacturing industry. Brazing and soldering techology is a welding technology that connects the base materials together with the help of liquid material filling the gap between the solid base materials and diffusing them to each other, which is widely used in industries such as aerospace, automotive manufacturing, household appliances, integrated circuits, and other industries, and it is also facing transformation and upgrading[1–9].

The flux serves to remove oxides from the surface of the base material and brazing and soldering material during the heating process, and to promote the wetting of the liquid material with the base material[10–11]. In the traditional process, brazing and soldering material and flux are usually used discretely, and the flux is volatile. Therefore, in order to ensure the quality of welding, it is necessary to add an excessive amount of flux before brazing and soldering. However, the volatilization of flux will pollute the air, and the residual flux after brazing and soldering is highly corrosive, which must be cleaned with a large amount of water or organic solvents, thus causing secondary pollution. In addition, the process of adding flux before brazing and soldering will lead to the difficulty of fully realizing the automated flexible production of brazed and soldered products.

Flux-coated brazing and soldering material is a kind of material-saving and emission-reducing composite material that has appeared in recent years, which is also a representative product of the development of brazing and soldering material processing technology. Flux-coated brazing and soldering material is made of material coated with a certain proportion of flux, and it has the following advantages compared with traditional brazing and soldering material. (1) It comes with flux, which realizes automatic and cooperative addition of flux during welding. The liquid flux breaks the oxidation film of flux at a fixed point, and then the filler metal

Received date: November 31, 2024
Foundation item: Henan Province Central Guiding Local Science and Technology Development Fund Project (Z20231811002)
Corresponding author: Dong Bowen, Ph. D., Professor, State Key Laboratory of High Performance & Advanced Welding Materials, China Academy of Machinery Zhengzhou Research Institute of Mechanical Engineering Co., Ltd, Zhengzhou 450001, P. R. China, Tel: 0086-371-67710507, E-mail: dbw1378@163.com

is positioned to fill in the seam, which is adapted to the development need of automated welding technology. (2) It reduces the dosage of flux and the emission of hazardous substances. On the one hand, flux-coated brazing and soldering material realizes the quantitative and constant ratio configuration of material and flux, which greatly reduces the amount of flux while ensuring the effectiveness of the flux. On the other hand, it reduces the process of cleaning joints, which improves the production efficiency and reduces the industrial sewage discharge.

In recent decades, worldwide scholars had conducted extensive and in-depth research on flux-coated brazing and soldering material, mainly focusing on the design, preparation technology, and application. In this paper, we systematically reviewed the research reports and research progress of flux-coated brazing and soldering material, and put forward the deficiencies in the current research and the development direction of flux-coated brazing and soldering material in order to provide references to the related fields of engineering research and technological development.

2 Design of Flux-Coated Brazing and Soldering Material

2.1 Ingredient design

The main role of the flux coating in the brazing and soldering process is to break the metal oxide film on the surface of the solid base material, reduce the surface tension between the liquid brazing and soldering material and the base material, and promote the wetting of the liquid material and the solid base material. The surface layer of the flux should be uniformly and closely coated around the brazing and soldering material, and has a certain bonding strength and plastic toughness[12].

Traditionally, the flux for brazing aluminum had been delivered as a dry powder. Handling of flux powder often results in workplace contamination, posing a hazard to workers. Mixtures require constant agitation to prevent segregation and agglomeration, thus influencing the uniformity of flux loading on parts to be brazed. Siggel et al[13] obtained a pre-dispersed concentrate of potassium fluoro-aluminate flux, which was a unique multi-constituent phase material with amorphous characteristic, an exceptionally low melting temperature, and high reactivity, resulting in a very homogenous flux coating and ultimately leading to excellent brazing results.

In the process of preparation, storage, and use of flux-coated silver brazing material, the brazing material and flux are at the same time in the high-temperature, high-pressure, acid, alkali, and salted environments, and the brazing material and the flux components (water-absorbent KF, KHF_2, and B_2O_3) may react, affecting the use of flux-coated brazing material performance. Zhang et al[14] studied the corrosion of flux and brazing alloy in the flux-coated silver brazing material and the effect of brazing corrosion on brazing performance, and found that the silver brazing material is in the environment of water-containing flux. It will be corroded by the flux, and the brazed joints of steel brazed with corroded silver brazing material will lose tensile strength. The addition of Sn in the brazing material can reduce the loss to a certain extent.

The flux is often used in the state of paste in order to make the flux uniformly adhere to the surface of brazing material. However, unreasonable concentration of flux will make the paste difficult to adhere to the surface of the brazing material, and the phenomena of agglomeration, slipping off, and so on will occur. Du et al[15] studied the adhesion behavior of paste flux on the surface of brazing material with different concentrations, as shown in Fig.1, and found that the adhesion layer of paste flux gradually thickens with the increase in concentration, a small amount of shrinkage occurs in the thin adhesion layer, and a large number of sliding off and shrinkage phenomena occur in the thick adhesion layer. As the concentration of paste agent increases, the additional pressure and hysteresis resistance decrease, yet the shrinkage increases. And the occurrence of shrinkage mainly depends on the adhesion tension and additional pressure.

The key to obtain a good braze with a flux-coated braze shim or wire is the binder. The binder needs to hold the flux on the shim stock or wire firmly, so it can be processed into whatever shape that the customer needs, without the coating chipping or flaking off. The binder also must burn off completely at a low temperature without carbon residue. An ideal flux coating binder vaporizes completely at a temperature below 204 °C[12]. The use of organic solvent-based adhesives is more prevalent in the worldwide research[16–26]. Most of the organic solvents have a certain degree of toxicity, and the organic colloid brazing and soldering process is easy to produce a large number of harmful gases or soot by thermal decomposition, resulting in serious pollution of the environment. The water-soluble adhesive is prepared in the consideration of environmental protection[27–34], but the water-soluble adhesive still belongs to hydrocarbons, more or less fumes are generated during the welding process. Lv et al[35] developed a kind of environmentally friendly ring-shaped flux-coated brazing material, which was prepared with flux coat solution for flux saturated solution (or supersaturated solution), as shown in Fig. 2. When the saturated solution becomes supersaturated solution, flux solution crystallizes, adjacent nuclei

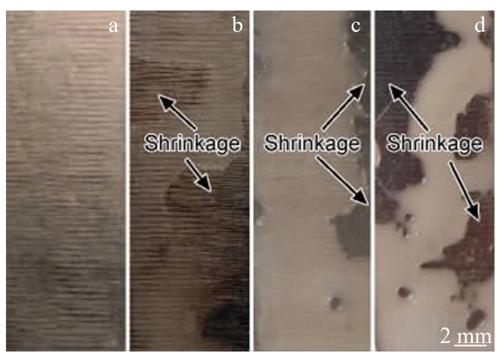

Fig.1 Adhesive state of paste flux suspension with different concentrations on surface of filler metal[15]: (a) 33.3%; (b) 50.0%; (c) 66.7%; (d) 75.0%

Fig.2 Environmentally friendly ring-shaped flux-coated brazing materials[35]

link together, and the crystals interact and grow, finally forming a flux coat with a certain degree of strength and hardness. The brazing material is firmly bonded together.

2.2 Structural design

Pre-formed brazing and soldering material is a material with a certain shape customized according to the shape of the weld[35]. The flux-coated brazing and soldering material usually appears in the pre-formed form, including strips, rings, squares, and arcs, as shown in Fig. 3. With the gradual expansion of the application field of welding technology, the structure of flux-coated brazing and soldering material is also becoming more and more diversified. Shin et al[36] introduced a flux laminated strip, which exhibited similar melting characteristics to flux-cored and flux-coated alloys. The new product is fabricated by four processes: embossing of strip, multi-bending of embossed strip, flux injection, and resizing of the material. The ability to produce a quality joint while reducing the amount of pre-braze and post-braze operations makes flux laminated strip an innovative eco-braze-materials. Pei et al[37] found a kind of self-brazing composite brazing material cake with helical skeleton to resist impact. The brazing material cake includes narrow band brazing material and narrow band material. The narrow band brazing material includes inner core and flux coat covered outside the inner core of brazing material. The narrow band brazing material and the narrow band alloy are continuously spaced and wound together, and they are interconnected to form a disk shape,

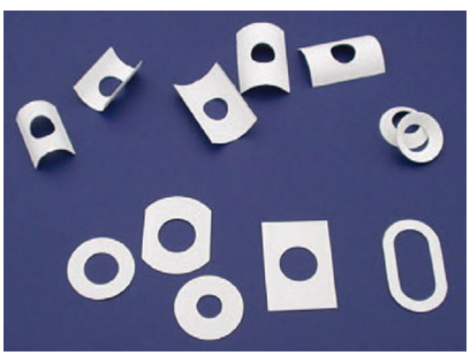

Fig.3 Flux-coated braze shims[12]

which has a better rigidity and stability of the structure. The Ag-Cu-Zn brazing material reacts with part of CuNi alloy to generate CuNiAgZn alloy when brazing, which can improve brazing strength and leave a spiral CuNi alloy isolation band after brazing, greatly improving stress release and impact resistance of cemented carbide tooling. Hiroyoshi et al[38] provided a solder material that includes: (1) a spherical core that provides space between a joint object and its counterpart; (2) a solder coated layer, whose melting point is lower than that of the core, ensuring that the core remains solid during soldering. Yao et al[39] found a solder with a plurality of individual wire strands braided together. The braided solder contains at least one wire strand where flux material is present.

The structural design of flux-coated brazing materials is usually with functional requirements. Different microstructures are formed on the surface of brazing material when it is processed. Du et al[40] investigated the effect of different microstructures on the adhesion of paste fluxes. Wang et al[41] found a flux-coated brazing material, with a brazing material inner core inside the flux coat, including a moisture-proof layer, a rust-proof layer, an active layer, a deoxidized layer, and a thermally-stabilized layer. Zhang et al[42] found a moisture-resistant and rust-resistant flux brazing ring, which contains a flux core, a metal coating plated on the periphery of the flux core, a highly active brazing flux layer covered on the periphery of the metal coating, a weakly moisture-absorbent brazing flux layer covered on the periphery of the highly active brazing flux layer, and a moisture-resistant outer layer adhered on the periphery of the weakly moisture-absorbent brazing flux layer. Long et al[43] found a flux-coated brazing ring with anti-skid bumps, wherein the inner ring of the flux coat was equipped with raised anti-skid bumps, effectively increasing friction and providing a good resistance to friction. Long et al[44] found a flux-cored brazing rod with a protective film. The protective film can not only avoid the flux-cored brazing rod from absorbing moisture from the seams, saving storage costs and energy, but also effectively prevent the surface oxidation of the seamed flux-cored brazing rod, improving the quality of the brazed joint. At the same time, the flux contained in the protective film can restore the oxidized brazing material alloy skin. And to a certain extent, it is also conducive to the wetting and spreading of brazing material.

Like electrodes, the flux on the surface of flux-coated brazing and soldering material can also participate in the alloying of the weld. Zi et al[45] studied the effect of Zn powder and Mn powder added to the flux on the resistance of brazed joints of A3 steel using H68 and H62 as the base brazing materials and dehydrated borax as the flux. They found that the Zn powder and Mn powder in the flux can make the brazed joints to be alloyed, improving the performance of brazed joints. Long et al[46] found a nickel core flux casing brazing coating material, consisting of a nickel inner core, a flux casing layer, a hardened layer, and a protective layer in order from the inside to the outside, with the flux casing layer containing cemented carbide particles and metal powders. Pei et al[47] found an in-situ synthesized metal-clad flux-coated silver brazing material, with the flux coat consisting of 5%–10% monolithic boron micropowder, 5% – 10% sodium borohydride, 15%–30% potassium fluoroborate, 25%–40% boronic anhydride, 10% – 30% sodium fluoride, 2% – 4% potassium fluorohydride, 1%–5% copper sulfate, 0.1%–2% polystyrene, and 0.2%–2% dibutyl phthalate. Zhong et al[48] found a wear-resistant flux-coated composition with diamond as a wear-resistant reinforcing material and transition metal oxides used as the filler material. And when used for soldering or brazing coating, the diamond forms a wear-resistant coating, while the presence of the filler material facilitates the reduction of thermal damage to the diamond and improves its brazing activity, reducing the coefficient of linear expansion of the molten metal.

3 Preparation Technique of Flux-Coated Brazing and Soldering Material

Coating a paste like flux mixture on the surface of the brazing and soldering material and drying it through a certain method can obtain the flux-coated brazing and soldering material. The most critical process is the coating process. The most widely researched coating techniques for flux coat include pressure coating, spray coating, and molten attachment. The filler metal and flux are physically combined, and the characteristics of these three methods are compared, as shown in Table 1.

3.1 Pressure coating

The pressure coating is a process that refers to the forming techniques of coating electrodes, using machinery to apply coating materials at high speed to the surface of strip-shaped brazing materials, and making them into coating materials. It is mainly used for the preparation of strip-shaped coating materials. Xie et al[49] prepared flux-coated brass brazing material using pressure coating method, which has good brazing process performance, moisture resistance, and toughness. The flowability of the brazing material is good, and the shape is beautiful, which can completely replace HS221 brass brazing material. Achitei et al[50] presented the technical steps to obtain new electrodes, made by Cu-Zn alloy, coated with one flux layer, which might be used to welding-brazing of thin plates from ferritic steels, with applications in automotive industry. Shen et al[51] found a continuous preparation system for flux-coated brazing materials, which was designed for the welding core with small diameter and thin flux coating. It achieves synchronous alignment of the welding core, coating, and cutting of the coating, therefore improving the automation level of coating and pressing.

3.2 Spray coating

The spraying process employs a compressed air stream to atomize the flux paste and to coat the surface of the brazing and soldering material under the air flow, which can be used for the preparation of flake flux-coated brazing and soldering material. Wojdat et al[52] presented the results of the possibility of Nocolok flux deposition to aluminum substrates using the low-pressure cold gas spraying method, as shown in Fig.4. An innovative method of applying flux in the form of a powder without organic adhesive additives was proposed, allowing strict control of the deposited material. The spray coating technique can also be used to prepare the ring-shaped and granular flux-coated brazing and soldering material[53–58], in which the flux solution was sprayed one or more times onto the surface of the rings or granules in a constant rolling motion, dried, cured, and shaped.

3.3 Molten attachment

Molten attachment involves a uniform mixture of heated and melted powder flux. The melted flux has a high adhesive force, which can be attached to the brazing and soldering material as a coating. Long et al[59] provided a device and method for manufacturing a coated welding rod. The heated welding rod enabled the granular flux to be formed into a viscous glassy state, so the flux could be adhered directly to the surface of the welding rod. Long et al[60] also found an efficient flux-coated brazing material with strong adhesion, whose surface was coated with a layer of an inorganic binder in a hot molten state. The prepared powder flux was uniformly adhered to the outside of the binder, and the flux coating was formed after drying.

4 Application Status of Flux-Coated Brazing and Soldering Materials

Flux-coated brazing materials integrate the structure and function of pre-positioned composite brazing materials and flux, which can improve the efficiency of flux use and brazing, and reduce the emission of flux, and their popularization and application is illustrative of a general trend[61]. Flux-coated ring can be used for brazing or soldering thin-walled piping systems in automobile, home appliance, locomotive, machinery, and aerospace industries, which is made of thin wire or thin narrow band brazing and soldering material wound. Pipeline weld seam coincides with the induction process. With the induction process to realize the piping system, quantitative, timed, fixed-temperature, positioning, and efficient automated brazing can be achieved, saving 25% of the brazing and soldering material[35,62–65], as shown in Fig. 5. Flux-coated brazing rods are mainly used in

Table 1 Characteristics of different coating techniques

Coating technique	Adhesive force	Thickness/mm	Efficiency	Applicability
Pressure coating	Medium	0.5–1.0	High	Just strip
Spray coating	Weak	Various	Low	Various
Molten attachment	Strong	0.1–1.0	Medium	Various

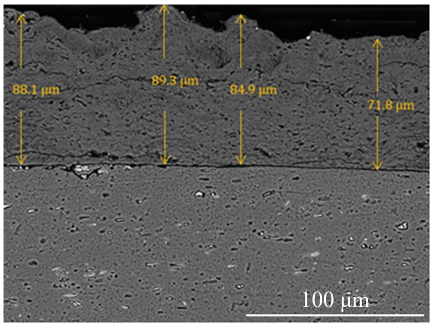

Fig.4 Micrograph of the coating[52]

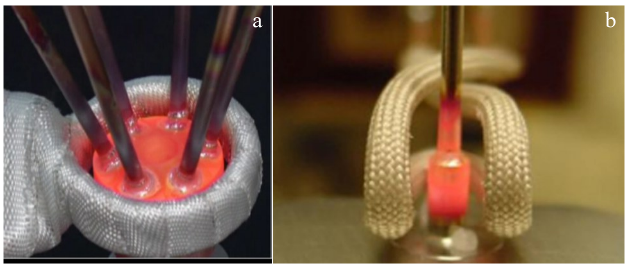

Fig.5 Induction brazing process of flux-coated filler metal ring[35]: (a) air conditioning distributor[62]; (b) refrigerator Bondi tube

flame brazing. Abtan et al[66] brazed 316 stainless steel to commercial pure copper using flux-coated low-silver-content filler with 20% Ag. A ferrite barrier layer was made on the stainless steel side, and an excellent brazed joint was produced. The results of the brazing process showed that using flux-coated low-silver brazing technique could produce strong joints with satisfactory mechanical properties. This technique was a cost-effective alternative to high-priced brazing fillers with high silver content. The heat distribution was simulated by geometrical models using ANSYS and Solidworks software to analyze penetration depth, joint quality, surface cracks, and the relation between molten filler density and wetting process, as shown in Fig.6.

A large number of derived applications have been generated using flux-coated brazing and soldering material. In the integrated circuit industry, surface coated flux solder balls increase the interconnect performance of the leadframe[67–69].

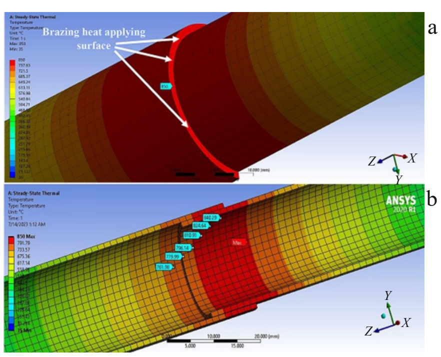

Fig.6 ANSYS heat distribution models of brazing heat applying surface (a) and brazing seam (b) with heat prop locations[66]

In the motor industry, conductive bars are coated with fusible bonding flux and are inserted into the upper through-holes, slots, and lower through-holes, so the conductive bars are integrally bonded into the upper through-holes, slots, and lower through-holes, following the fusion and solidification of the fusible bonding flux, which improves the safety of ultrahigh-speed induction motors[70]. In the heat exchanger industry, an aluminum extruded multi-cavity flat tube used in an automotive heat exchanger has excellent brazing characteristics. At least one of the flat surfaces of aluminum extruded multi-cavity flat tube is coated with a flux consisting of a brazing flux and a synthetic resin[71]. In the foundry industry, all free surfaces of the furnace charge are coated with a layer of flux. The flux layer removes the naturally occurring oxide film from the furnace charge surface as well as provides a cover flux against oxidation in the melt pool[26]. In the drilling industry, a method of manufacturing a drill body based on a metal matrix composite includes loading a matrix powder into a bit body mold, loading a flux-coated binder into the mold on top of the matrix powder to form a load assembly, and heating the load assembly to allow the binder to infiltrate into the matrix powder[72].

5 Conclusions and Outlook

As a kind of material-saving and emission-reduction material, flux-coated brazing and soldering material conforms to the needs of social development. At present, flux-coated brazing and soldering material has made certain progress in design and preparation technique, and has been applied on a large scale in refrigeration, automobile, and electrical appliance industries. However, there are still some deficiencies in the research and application, and it is suggested to solve the following problems in the future.

1) The standards related to flux-coated brazing and soldering material are still lacking. At present, there are only three group standards led by our team, which stipulate the models and classifications, technical requirements, test methods, inspection rules, and product life cycle evaluation of flux-coated brazing material, as follows: (1) T/CMES 02001-2022, flux-coated copper base brazing filler metals issued by Chinese Mechanical Engineering Society; (2) T/HNNMIA 5-2020, technical specification for green-design product assessment-flux cored brazing filler metals; (3) T/HNNMIA 10-2018, flux-coated silver brazing filler metals issued by Henan Provincial Nonferrous Metals Guild. However, the product quality is uneven in the market and the product batch stability is not good. The lack of preparation technique standards seriously restricts the popularization and application. There is an urgent need to systematically establish a quality evaluation method for the preparation stability, product consistency, and green environmental protection of flux-coated brazing and soldering material, in order to adapt to the demand for high-quality, high-efficiency, and green brazing of robots and automated brazing, and to promote the quality of flux-coated brazing and soldering material and the related technological progress.

2) The mechanism of synergistic reaction between flux coating and brazing and soldering material is not clear. In the process of brazing and soldering, metal/flux coating synergistic reaction and caulking mechanism are complex. The surface oxide film structure, composition, densification, and thickness of different metal or alloy are not the same. Flux to remove the oxide film on the surface of the base material and the mechanism of change in the interfacial tension between the liquid metal in the flux and the base material need to be further investigated in order to improve the composition of flux-coated brazing materials and to expand the range of applications.

3) The alloyed flux-coated brazing and soldering material is rarely reported. Because the high-performance brazing and soldering material is difficult to process and mold, and welding seam composition is difficult to adjust flexibly, the concept of flux-coated electrodes in the field of fusion welding is introduced into the process of flux-coated brazing and soldering material. The alloying elements are supplemented to the flux coating, giving full play to the advantages of flux-coated brazing and soldering material in facilitating the adjustment of flux ratio and controlling the welding seam composition, expanding the scope of flux-coated brazing and soldering material, and promoting flux-coated brazing and soldering material to approach the goal of welding automation, green development, and intelligent manufacturing.

4) The form of flux-coated brazing and soldering material is not rich enough. Brazing and soldering material is usually processed into different geometrical shapes according to the requirements of welding process and material processing performance, and the selection of suitable flux-coated brazing and soldering material geometrical shapes can simplify the process and improve the brazing quality. With the development of society and the diversification of industrial product structures, welding structure is more complex, and the transformation of flux-coated brazing and soldering material into a more suitable geometry has become a renewed industry research direction.

References

1 Long Weimin, Li Shengnan, Du Dong *et al*. *Rare Metal Materials and Engineering*[J], 2019, 48(12): 3781

2 Long Weimin, Sun Huawei, Qin Jian *et al*. *Electric Welding Machine*[J], 2018, 48(3): 25 (in Chinese)

3 Long Weimin, Sun Huawei, Bao Li *et al*. *Welding Technology*[J], 2016, 45(1): 59 (in Chinese)

4 Long Weimin, Sun Huawei, Bao Li *et al*. *Welding Technology*[J], 2015, 44(9): 12 (in Chinese)

5 Long Weimin, Zhang Qingke, He Peng *et al*. *Welding & Joining*[J], 2015(2): 1 (in Chinese)

6 Long Weimin, Zhang Qingke, Zhu Kun *et al*. *Welding & Joining*[J], 2014(1): 3 (in Chinese)

7 Long Weimin, Cheng Yafang, Zhong Sujuan *et al*. *Welding & Joining*[J], 2010(1): 20 (in Chinese)

8 Dong Bowen, Zhong Sujuan, Pei Yinyin *et al*. *Rare Metal Materials and Engineering*[J], 2021, 50(10): 3527

9 Wang Meng, Zhang Guanxing, Zhong Sujuan *et al*. *Rare Metal Materials and Engineering*[J], 2021, 50(8): 2859 (in Chinese)

10 Wang Bo, Long Weimin, Lou Yinbin *et al*. *Rare Metal Materials and Engineering*[J], 2022, 51(5): 1919 (in Chinese)

11 Zhao Yue, Long Weimin, Huang Sen *et al*. *Rare Metal Materials and Engineering*[J], 2021, 50(11): 3857

12 Harris Daniel. *Welding Journal*[J], 2007, 86(3): 53

13 Siggel A, Rudolph J, Lau C *et al*. *9th Conference on NDT In Material Testing*[C]. Düsseldorf: DVS Media GmbH, 2018: 33

14 Zhang Guanxing, Lu Quanbin, Zhou Shisheng *et al*. *Precious Metals*[J], 2017(A1): 70 (in Chinese)

15 Du Quanbin, Long Weimin, Lu Quanbin *et al*. *Journal of Materials Engineering*[J], 2017(11): 96 (in Chinese)

16 Zhong Sujuan, Sun Huawei, Zhang Lei *et al*. *China Patent*, CN106271226B[P]. 2018 (in Chinese)

17 Pei Yinyin, Shen Yuanxun, Zhao Chenfeng *et al*. *China Patent*, CN106271203B[P]. 2018 (in Chinese)

18 Wang Xiaorong, Chen Fei, Fan Zhonghua *et al*. *China Patent*, CN109483082B[P]. 2021 (in Chinese)

19 Darwin H Scott. *US Patent*, US07337941B2[P]. 2008

20 Motohiro Onitsuka, Yoko Kurasawa, Toshihisa Kugi *et al*. *US Patent*, US10688603B2[P]. 2020

21 Motohiro Onitsuka, Yoko Kurasawa, Hiroyuki Yamasaki *et al*. *US Patent*, US11413711B2[P]. 2017

22 Yoko Kurasawa, Hiroaki Iseki, Kenta Nakajima. *US Patent*, US11858072B2[P]. 2024

23 Yoko Kurasawa, Motohiro Onitsuka, Hisashi Tokutomi *et al*. *US Patent*, US11648631B2[P]. 2023

24 Motohiro Onitsuka, Yoko Kurasawa, Hiroyoshi Kawasaki. *US Patent*, US11292089B2[P]. 2022

25 Takashi Watsuji, Haruzou Katou, Ken Matsumura *et al*. *US Patent*, US6497770B2[P]. 2002

26 Alfred Siggel, Douglas Kenneth Hawksworth. *US Patent*, US10730150B2[P]. 2020

27 Long Weimin, Lv Dengfeng, Zhu Kun *et al*. *China Patent*, CN104907728B[P]. 2017 (in Chinese)

28 Long Weimin, Lv Dengfeng, Dong Xian *et al*. *China Patent*, CN104907724B[P]. 2017 (in Chinese)

29 Qian Shijian, Lou Yinbin, Sun Ke *et al*. *China Patent*, CN112247400B[P]. 2022 (in Chinese)

30 Motohiro Onitsuka, Yoko Kurasawa, Hiroyuki Yamasaki *et al*. *US Patent*, US11413711B2[P]. 2022

31 Placido Garcia-Juan, Hans-Walter Swidersky, Andreas Becker. *US Patent*, US8978962B2[P]. 2015

32 Masahiro Kojima, Futoshi Watanabe, Atsuhiko Tounaka *et al*. *US Patent*, US6059174A[P]. 2000

33 Taketoshi Toyama, Ryoichi Sanada, Takashi Hatori *et al*. *US Patent*, US7534309B2[P]. 2009

34 Yoshiharu Hasegawa, Shoei Teshima, Ichiro Taninaka *et al*. *US Patent*, US6234381B1[P]. 2001

35 Lv Dengfeng, Chen Baoyu, Zhong Sujuan *et al*. *Welding & Joining*[J], 2017(4): 17 (in Chinese)
36 Shin Y S, Lee Y S, Lee C H. *Materials Science Forum*[J], 2007, 544–545: 219
37 Pei Yinyin, Lv Dengfeng, Zhong Sujuan *et al*. *China Patent*, CN108188615B[P]. 2020 (in Chinese)
38 Hiroyoshi Kawasaki, Shigeki Kondo, Atsushi Ikeda *et al*. *US Patent*, US10675719B2[P]. 2020
39 Yao Siuyoung, Brian Taggart. *US Patent*, US7780058B2[P]. 2010
40 Du Quanbin, Long Weimin, Lu Quanbin. *Transactions of the China Welding Institution*[J], 2017(2): 37 (in Chinese)
41 Wang Liwen. *China Patent*, CN211516468U[P]. 2020 (in Chinese)
42 Zhang Lei, Lv Dengfeng, Bao Li *et al*. *China Patent*, CN108212583B[P]. 2023 (in Chinese)
43 Long Weimin, Lv Dengfeng, Dong Xian *et al*. *China Patent*, CN204565443U[P]. 2015 (in Chinese)
44 Long Weimin, Zhong Sujuan, Dong Bowen *et al*. *China Patent*, CN105081599B[P]. 2022 (in Chinese)
45 Zi Shuyan, Bai Ling, Li Zhichao *et al*. *Journal of Liaoning Technical University* (*Natural Science*)[J], 2004(1): 107 (in Chinese)
46 Long Weimin, Zhang Guanxing, Li Yong *et al*. *China Patent*, CN114850726B[P]. 2023 (in Chinese)
47 Pei Yinyin, Zhong Sujuan, Lv Dengfeng *et al*. *China Patent*, CN108406162B[P]. 2020 (in Chinese)
48 Zhong Sujuan, Dong Bowen, Qin Jian *et al*. *China Patent*, CN110961830B[P]. 2021 (in Chinese)
49 Xie Changlin, Wang Li. *Welding Technology*[J], 2001(3): 30 (in Chinese)
50 Achitei D C, Vizureanu P, Minciuna M G *et al*. *Materiale Plastice*[J], 2015, 52(2): 165
51 Shen Yuanxun, Ma Jia, Zhang Lei *et al*. *China Patent*, CN106112314B[P], 2018 (in Chinese)
52 Wojdat T, Winnicki M, Pabian J. *Materials Science Poland*[J], 2022, 40(4): 114
53 Long Weimin, Zhong Sujuan, Lv Dengfeng *et al*. *China Patent*, CN108326475B[P]. 2020 (in Chinese)
54 Dong Xian, Zhong Sujuan, Dong Hongwei *et al*. *China Patent*, CN115430947B[P]. 2024 (in Chinese)
55 Bao Li, Lv Dengfeng, Ding Tianran *et al*. *China Patent*, CN108212583B[P]. 2023 (in Chinese)
56 Long Weimin, Lv Dengfeng, Dong Xian *et al*. *China Patent*, CN104759781B[P]. 2017 (in Chinese)
57 Sun Huawei, Pei Yinyin, Lv Dengfeng *et al*. *China Patent*, CN208261053U[P]. 2018 (in Chinese)
58 Philippe Schmitt, Boris Bosi. *US Patent*, US8696829B2[P]. 2014
59 Long Weimin, Zhong Sujuan, Dong Hongwei *et al*. *US Patent*, US11660709B2[P]. 2023
60 Long Weimin, Lv Dengfeng, Ma Jia *et al*. *China Patent*, CN104907721B[P]. 2017 (in Chinese)
61 Long Weimin, Sun Huawei, Zhong Sujuan *et al*. *Welding Technology*[J], 2016(5): 17 (in Chinese)
62 Wang Bo, Long Weimin, Wang Mengfan *et al*. *Crystals*[J], 2021, 11(9): 1045
63 Zhang Guanxing, Zhong Sujuan, Cheng Yafang *et al*. *Transactions of the China Welding Institution*[J], 2017, 38(12): 33 (in Chinese)
64 Wang Bo, Long Weimin, Zhong Sujuan *et al*. *Electric Welding Machine*[J], 2021, 51(2): 1 (in Chinese)
65 Huang Junlan, Long Weimin, Dong Xian. *Hot Working Technology*[J], 2021, 43(3): 141 (in Chinese)
66 Abtan A A, Mohammed S M, Alshalal I. *Advances in Science and Technology Research Journal*[J], 2024, 18(1): 167
67 Lei Shi. *US Patent*, US9502337B2[P]. 2016
68 Jimmy Hwee Seng Chew, Kim Hwee Tan. *US Patent*, US6550666B2[P]. 2003
69 Tan Kim Hwee, Romeo Emmanuel P Alvarez. *US Patent*, US6510976B2[P]. 2003
70 Hong Seungsu, Yang Seongu. *US Patent*, US8587178B2[P]. 2013
71 Shoei Teshima, Yoshiharu Hasegawa, Ichiro Taninaka *et al*. *US Patent*, US6800345B2[P]. 2004
72 Cai Mingdong. *US Patent*, US11358218B2[P]. 2022

药皮钎料研究进展及应用

程亚芳[1,2]，董博文[2]，董　显[2]，钟素娟[2]，龙伟民[2]

(1. 郑州大学 材料科学与工程学院，河南 郑州 450001)

(2. 中国机械总院集团郑州机械研究所有限公司 高性能新型焊接材料全国重点实验室，河南 郑州 450001)

摘　要：药皮钎料是近年来出现的一类节材减排型复合钎料，体现了钎料加工技术的进步与发展趋势，受到焊接工作者的高度关注。本文主要综述了有关药皮钎料设计、制备技术和应用的研究报道，提出了目前研究的不足，并展望了药皮钎料未来的研究方向，主要集中在药皮钎料的标准、药皮与钎料金属协同反应机理、药皮钎料的合金化以及药皮钎料的形态四个方面，以期为焊接领域相关研究和技术发展提供参考信息和理论指导。

关键词：药皮钎料；结构设计；制备技术；合金化；标准

作者简介：程亚芳，女，1983 年生，博士生，正高级工程师，郑州大学材料科学与工程学院，河南 郑州 450001，E-mail：yephon099@sina.com