

On the direct use of recovered scrap copper and saving copper with aluminum in the Chinese cable industry

Huang Chongqi

(Shanghai Electric Cable Research Institute, Shanghai 200093, China)

Abstract: The copper consumption by the Chinese cable industry amounted to 354×10^4 t in 2006, taking over 70 % of the total copper consumption in China in that year. At present, making copper rod directly from recovered scrap copper and saving copper with aluminum have become topics of general interests in the Chinese cable industry. The quality of the copper conductors in the industry is declining, resulting in sharp decrease in the rate of qualified wire and cable products. More and more copper wires are drawn from the rods made directly from scrap copper. The manufacturers know well some of the wires or rods are unqualified products though, they continue to use or produce products not complying with standards in order to make profits. Now the consumption of copper-clad-aluminum and copper-clad-steel is growing gradually. In 2006, the consumption of copper-clad-aluminum in China amounted to ca. 5×10^4 t. But in some applications, neither the common understanding between buyer and supplier nor the results of feasibility study are achieved in the product orientation and technical/economic feasibility in terms of saving copper with aluminum. This paper presents the status-quo, problems arisen and suggestions in terms of making copper rod directly from recovered scrap copper and saving copper with aluminum, in a view to promote these two topics of general interests to go toward a virtuous circle.

Key words: scrap copper; recovery; using aluminum; saving copper; rod making; the cable industry

1 Outline of the production and application of copper/aluminum conductors

In the economic circle of cable industry, the production and application of copper conductors are significant to economy, save resources and energy and improve environment, because they are closely related to the national economy and every single person. In 2006, the consumption of copper conductors in China is 354×10^4 t (Table 1 and Table 2)^[1]. It is good news that the output increases after it has become No. 1 in the world. But it is absolutely necessary to pay attention to the quality of copper conductors' production and its passive effect on environment. From Table 2, we can find power cables consume the most copper conductors, and then come the wires and cables for electrical installation and winding wires. But the increasing speed of the copper consumption of winding wires is the fastest. In Table 3, it is can be found that the production of refined copper in China in 2006 is 300×10^4 t and imported and domestically recovered scrap copper is 562×10^4 t (total metal content in the scrap copper ca. 168×10^4 t)^[2-4]. Cable industry uses

most refined copper and the use of copper rods made directly from scrap copper has been increasing in recent years. No one knows how many copper rods made directly from scarp copper are used every year. Some said it took 1/3 of the total copper consumption, while others said it took 1/2 of the total copper consumption. It remains a mystery because of the statistics difficulty and needs further investigation. The installed capacity for low oxygen copper rods, OF (oxygen free) copper rods for the electrical application in China can be found in Table 4. The installed capacity of low oxygen copper rods in 2006 has been 181 assembly production lines and the total production capacity has been about 660×10^4 t. In recent years, because of the generous profits gained from scarp copper price, the continuous casting and rolling low oxygen copper rods assembly lines (about 160 assembly production lines) rapidly increase and distribute over the whole country. Most of them uses scrap copper to make recovered rods directly. As for UPCAST copper rods assembly production lines, the production capacity has reached 400×10^4 t according to the data in 2004. The production capacity of those two rods is $1\ 000 \times 10^4$ t.

Received 24 October 2007

Table 1 Variation in the yearly consumption of copper/aluminum conductors in China

Conductor	10 ⁴ t															
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Copper	70	78	84	95	114	123	130	143	150	172	200	210	240	285	312	354
Aluminum	22	22	24	25	27	28	32	35	43	58	76	85	93	98	102	107

Table 2 Total copper consumption by copper, copper alloy and bimetallic conductors and shares of the individual wire and cable products in China in 2006

Total copper consumption by conductors/10 ⁴ t	Shares of the individual wire and cable products (10 ⁴ t / %)				
	Bare conductors	Wire and cable for electrical installation	Power cables	Communications wire and cable	Winding wires
354	20/5.65	104/29.4	115/32.5	16/4.52	99/28.0

Table 3 A survey of copper conductors, refined copper and Scrap copper in China in 2006^[1,5]

Variation	Description	Amount or percentage	Remarks
	Total consumption by conductors	354 × 10 ⁴ t	
Copper used for conductors	Percentage of the consumption by conductors in the sum of consumption of refined copper and scrap copper	72 %	$\frac{354}{380 + 98.8 + 12} \times 100$
Refined copper	Production of refined copper	300 × 10 ⁴ t	
	Imports of refined copper	82 × 10 ⁴ t	
	Exports of refined copper	24 × 10 ⁴ t	
	Apparent supply of refined copper	358 × 10 ⁴ t	Decreased by ca. 5 % from 2005
	Consumption of refined copper	380 × 10 ⁴ t	
Scrap copper	Imported wastes containing copper	494 × 10 ⁴ t (corresponding to 98.8 × 10 ⁴ t copper)	1. Total metal content in the scrap copper ca. 168 × 10 ⁴ t
	Commercially available scrap copper recovered domestically	68 × 10 ⁴ t	2. The peak of the recovery of scrap copper in China is expected after 2010
	Production of recovered copper	80 × 10 ⁴ t	Increased by 29 % from 2005
	Percentage of the production of recovered copper in the consumption of refined copper	21 %	

Note: Prediction of the production of scrap copper in 2007: as the production capacity of recovered copper to be built is ca. 30 × 10⁴ t, the production of recovered copper in 2007 will grow at a rate not less than 30 %. The production of recovered copper at the end of 2007 is predicted to be over 100 × 10⁴ t.

Table 4 A rough estimation of the installed capacity for low oxygen copper rods, OF copper rods and aluminum rods for the electrical application in China (up to 2006)

Low oxygen copper rods	Lines purchased from abroad	21; ca. 150 × 10 ⁴ t
	Domestically made lines	160; ca. 510 × 10 ⁴ t
	Total	660 × 10 ⁴ t
OF copper rods	ca. 400 × 10 ⁴ t (data in 2004)	
Electrical aluminum rods	ca. 240 × 10 ⁴ t (ca. 200 lines, data in 2004)	

Now, because the copper resource in China is in shortage, the original copper resource is greatly dependent on foreign resources and the supply of scrap copper is not enough. The domestic recovery of scrap copper hasn't reached the peak, while it is estimated that the copper price is going to be higher than the highest price in 2006^[6]. There are not restrictive im-

port rules for scrap copper in China now.

The consumption of aluminum conductors for electrical application in China in 2006 was 107 × 10⁴ t (Table 5). The aluminum conductors are mainly used for overhead conductors. The aluminum consumption of other cables and wires only takes 20 % of the total consumption. Not many copper power cables are replaced by aluminum power cables and the replacing trend is not obvious. There is a rough estimation about the installation capacity for aluminum rods for the electrical application. According to the data in 2004, there have been about 200 assembly production lines and the production capacity was about 240 × 10⁴ t. As the aluminum ingot export policy changed in recent years, the aluminum rod production capacity increased and the number of new continuous casting and rolling aluminum assembly production lines went up. The aluminum resource and production situation are much better than

copper. The output of electrolytic aluminum in 2006 was 935×10^4 t which had been No. 1 in the world during the past five years. The aluminum material output in 2006 was 815×10^4 t which had been the No. 2 in the world during the past five years. In 2006 and 2007, the supply of domestic aluminum industry, from alumina to electrolytic aluminum and aluminum product processing market is over the demand. The primary policy for aluminum industry development is: “The

Table 5 Total aluminum consumption by aluminum and aluminum alloy conductors and shares of the individual wire and cable products in China in 2006

Total aluminum consumption by conductors/ 10^4 t	Shares of the individual wire and cable products		
	Overhead conductors and ground wires (10^4 t /%)	Overhead insulated conductors (10^4 t /%)	Flat wires, busbar, braiding wires, insulated conductors in wire and cable, enamel wires, bimetallic conductors and others (10^4 t /%)
107.0	85/79.5	10.0/9.3	12.0/11.2

According to above production and application of electrical copper conductors, we remind the investigators for copper conductor production to be cautious and do not investigate blindly, especially for copper rods made directly from scrap copper. Because of the different technical requirements for cable and wire products, the cable industry will not completely use rods made directly from scrap copper as the quality of rods made directly from scrap copper is worse than the rods made from electrolytic copper. To improve the quality of cable and wire products and the technical economy benefits of production, the quality for rod choice is the most important. If the present behindhand production method is adopted without accelerating technology reform, the products will be scrap copper rods with low quality and low standard, which will not be trusted by the cable industry and permitted by wire and cable product standards and the market. It wastes scrap copper, increases the national energy consumption, increases the safety hidden trouble in the application and raises pollution. The scrap copper resource is limited both in and outside China. Especially the domestic scrap copper recovery hasn't reached its peak. This year, the supply of scrap copper is in shortage. The blind expansion of assembly production line will probably meet the problem of lacking raw materials and cause economic lose. At present, the production capacity of low oxygen copper rods and OF copper rods has far over the needs.

2 Making electrical copper rods directly from scrap copper

The recovered copper in 2007 will increase fast and it brings an opportunity for recovered copper industry development. Recovered copper industry is an in-

main aim is to satisfy the domestic needs. The export of alumina, electrolytic aluminum, aluminum alloy and other primary aluminum products is going to decrease. The oversea development of aluminum resource and industry is advocated. We will try our best to save energy, reduce consumption, decrease pollution and support circular economy. It is required that the recovered aluminum must take 25 % of the aluminum total consumption in 2010 and the use ratio must increase”.

dustry beneficial to the state and people. It is the national need and should be supported by the state's policy and related parts' technology. It is the reality need to make electrical copper rods directly from scrap copper. The problem is how to do it well, namely, how to improve the copper rods' quality to satisfy the clients' and related standards' requirements and try to decrease pollution in production^[9-11].

2.1 The market share of copper rods made directly from scrap copper in the cable industry

If the quality, performance stability and finished products production ratio of copper rods made directly from scrap copper increase, they will take a great deal of market share (Table 6). Then both suppliers and buyers can make profits.

Table 6 The possible market share of the copper rods made directly from scrap copper in the cable industry

No.	Application	Wire diameter/mm	Share/%
1	Power cables, building wires, magnet wires	> 1.10	45.0
2	Communications wire and cable and magnet wires	0.4 ~ 1.10	20.0
3	Flexible cords and magnet wires	0.12 ~ 0.4	20.0
4	Magnet wires, electronic wires and communications wire and cable	< 0.12	15.0

Note: 1) Generally the 0.3 mm wire diameter is used as the criterion for judging the drawability of the copper rods made directly from scrap copper. The wires with diameter of 0.3 mm and above takes an adequate market share in the application in wire and cable products.

2) The copper rods used as conductors include low oxygen copper rod made from electrolytic copper by continuous casting and rolling, OF copper rod by UPCAST and OF copper rod by dip-forming. The copper rod made directly from scrap copper refers to mainly the low oxygen copper rod made by continuous casting and rolling (i. d. fire-refined high conductivity copper rod, short as FRHC rod)

The market of rods made directly from scarp copper is the applications with lower requirements for quality or wire of bigger diameter or profile wire, such as power cables, construction wires, copper busbar and copper tape. But it is hard to be accepted by the following industries without first-class quality, including enamel wires, electronic wires and communications wires.

There is an obvious distance of the scarp copper direct use rate between our country and the developed countries (Table 7). Our scarp copper direct use is still in the primary stage. With the co-efforts of our society, according to normal development, our country's scrap copper direct use rate is going to increase, including copper rods made directly from scrap copper.

Table 7 Comparison between China and developed countries in terms of direct use of scrap copper

Country	Direct use of scarp copper as multiple(s) of recovered copper
World average	2.0
China	1 ~ 1.5
USA	20
Italy	14
Japan	5.5

2.2 Difference between the rod made directly from scarp copper and that from electrolytic copper

Making copper rods directly from scarp copper is to classify, grade and pre-treat recovered scarp copper first, then melt scarp copper directly in melting furnace, finally continuously cast and roll or continuously cast scarp copper. It can save energy, simplify manufacturing procedure and the production cost is low. But it is more difficult to control the rods' quality than making rods by electrolytic copper. The purity of this kind of rods must be higher than 99.9%, and then it can be used for electrical products. The requirement for its electrical performance is the most important, also including the requirements for rollingability, drawability, annealability and surface quality. All those requirements set higher standards for scarp copper classification, grading, pre-treatment, melting technology and quality monitoring. Whether produced rods can satisfy the requirements for quality and environment depend greatly on the scarp copper pre-treatment, raw material grade, melting and three wastes treating devices, technology and monitoring the process. The copper purity of raw material for electrical wires and cables is more than 99.95% (No. 2 copper) and 99.99% (No. 1 copper, the impurity content ≤ 65 ppm (ppm is 10^{-6})). This is the standard accepted internationally.

The technical difficulty of making OF copper rods directly from scarp copper (including completely use scarp copper and use the mixture of scarp copper and electrolytic copper) is to control the oxygen content. The oxygen content can be less than 10 ppm when making copper rods (completely use electrolytic copper) by UPCAST, while it is very hard to reach that standard when making copper rods directly from scarp copper. It needs to control the oxidization of scarp copper and increase the reduction time of copper liquid. Besides, the cable manufacturers and clients have to pay attention to hydrogen brittleness and its checking. The technology of rods made by UPCAST, rod cracks and internal defects will directly influence wires' drawability. Graphite models are prone to break and auxiliary time and cost increase. Therefore, the technology of making copper rods directly from scarp copper hasn't been widely used in foreign countries.

2.3 The status-quo and problems arisen in terms of making copper rods directly from scrap copper in China

Under the market background of severe copper resource shortage in China, reasonably regulating making copper rods directly from scrap copper is going to be the developing and competition trend of copper conductor market and it abides by the circular economy developing strategy propose by the government. While, as the scarp copper in China is recovered from different channels, such as the scrap copper in Taizhou, Ningbo in Zhejiang Province, Nanhai, Qingyuan in Guangdong Province, Jinhai in Tianjin, etc. is mainly recovered from imported scarp copper; the scarp copper in Linyi in Shandong Province, Dashiqiao in Liaoning Province, Xinjin in Sichuan Province, etc. mainly consists of the domestic recovered scarp metal and its contents are very complex. There are many enterprises in China to make electrical copper rods directly from scrap copper. The production capacity is about 180×10^4 t (needs further investigation) which is composed of 50% of the total output of electrical copper rods. Because of the huge differences of raw materials, technologies and devices, the qualities of copper rods made directly from scarp copper are quite different. According to the investigation of several factories in some provinces, we find most of the factories do not have or have incomplete chemical analysis technology to test the copper content, let alone fast analysis. Some factories don't have any device to test the products' quality. The quality is totally out of control. The copper rod purity is 99.3% ~ 99.8%. Only few factories' products' purity is or is more than 99.9%. The chemical contents of copper rods are severely different one lot

from another. The most obvious problem is the electric conductivity is far from the requirement of related standards and the annealability of copper rods are different one lot from another, too. Those unqualified rods will definitely make chaos, bring passive effects on market and make factories which use cathode copper with high purity and standard cathode copper as raw material earn little or even loss profit. That is unfair. This kind of factories follows the wastes resource and severely pollutes the environment. The low-oxygen-bright copper rods are neither low-oxygen nor bright and cannot satisfy related quality standards. While there are some other factories adopt advanced technology and devices and use qualified scrap copper to produce electrical copper rods which can achieve the national standards. The environment protection in the process of making copper rods directly from scarp copper remains a big problem which is to be faced by Chinese recovery copper manufacturers and the bottleneck for the sustainable development of Chinese copper recovery industry. The environment problem is mainly the control of smoke gas. According to related regulations, the smoke gas pollution mainly consists of granular pollution and gas pollution. Nowadays, the recovery copper manufacturers in China have installed dust absorption devices and it is an effective control for granular pollution. While, as the recovered copper raw materials are complex, the dust adsorption effect is not very ideal. There are also many manufacturers don't have any environment protection equipment, which is a phenomenon of backward.

The recovered copper manufacturers in China haven't begun to control gas pollution, which needs us to pay attention to. Because of the complex raw materials, the gases generated by the burning of organic matter in the melting process will pollute the environment severely, especially those permanent organic pollution. This kind of pollution has drawn the whole world's attention. In 2006, some related units in China have tested the gas pollution of recovered copper manufacturers, including the test of dioxin.

Electrical copper rods are one of the basic materials of cable industry. The quality decrease of copper rods can be reflected in the finished product ratio of electrical wires and cables immediately. At present, as the quality of copper rods made directly from scrap copper is unqualified, the qualified ratio of wires and cables decrease sharply. According to the reports published by the quality monitoring departments in Guangdong Province, Hunan Province and Zhejiang Provin-

ce^[7-9], "nearly 80 % of the electrical wires and cables is unqualified, in which 49.6 % resistance of wires and cables is unqualified because of adopting unqualified copper rods made directly from scrap copper"; "the products unqualified ratio is 34.6 % . In the unqualified 35 wire and cable samples, the resistances of 25 samples are over the standard which takes 71 % "; "the unqualified ratio is over 60 % because of doing shoddy work and using inferior materials". If the situation cannot be improved, it will affect every family in our country and cause very serious consequence. This problem has drawn the attention of copper rod and cable manufacturers and it is hoped the situation can be improved in a short time.

The reasons^[13] for the problems caused by electrical copper rods made directly by scrap copper are various, including raw materials, equipment, production technology, policy, regulations, management and standards, etc. Regarding technology only, the main reasons of affecting copper rods quality and cause environment pollution are shown below.

1) The preliminary treatment of scrap copper. It involves the classification and grading^[14,15] of scrap copper first, and then it involves the method and equipment of preliminary treatment. In some of the disposal fields with many scrap electrical wires and cables, for the lack of mechanized cable recovery equipment, it is a waste that some scarp copper wires are mixed with other low grade scrap copper. Some of the copper wires are plated with Sn, Pb-Sn alloy, Ni, Ag or enamel, while some of them are covered with steel or aluminum. These metals, alloys and organic enamels will directly affect the copper rods' quality and cause environment pollution. If all these plates, coats, covered metals and organic matters are put into melting furnace, it will definitely decrease the quality of copper rods and pollute the environment. Therefore, we have to pay attention to when to process plunger separation (outside or inside melting furnace), how to process (chemical or firing process) and with what equipment.

2) The melting technology, the three wastes treatment technology and their equipment. Preliminary treatment, melting technology and their equipment is the key point to improve the quality of copper rods made directly from scrap copper. Preliminary treatment and melting furnace are the pollution sources.

To solve all the above technical problems generated in the early stages of scrap copper recycling use, it is necessary that all the related parts work together to study recovery technology and design recovery equipment.

2.4 The copper rods made directly from scrap copper can satisfy the requirements of standard

The copper rods made directly from scrap copper can satisfy the requirements of national and international standards. It can satisfy the clients' requirements in a certain scope. Since the FRHC method was found by La Farga Lacambras S. A company in Barcelona, Spain and Continuus-properzi S. P. A company in Italy and used to make copper rods with 100 % scrap copper by continuous casting and rolling 20 years ago, it has been accepted and adopted by other countries. It is mainly used to make expansion of electrolytic copper rods continuous casting and rolling assembly production lines, increase the categories of copper rods made directly from scrap copper and build new assembly production lines to make copper rods directly from scrap copper by continuous casting and rolling. According to the latest news, FRHC method will be imported to Ganzhou Jiangwu New Type Alloy Material Co., Ltd. (the production capacity is 12×10^4 t/a) which is under construction, and then Tianjin TPCO Copper Industry Co., Ltd. (has the same production capacity), etc. are planning to import this method. Through import, absorption and recreation, it will absolutely improve the production and application level of making electrical copper rods directly from scrap copper in our recovery industry and cable industry.

2.4.1 The raw material of scrap copper

To make electrical copper rods, the requirements for scrap copper raw material and preliminary treatment are comparatively high and the classification and grading should be refined.

1) Super-grade and grade 1 granular scrap copper. This kind of raw material (wire core of the wire and cable) consists of clean copper wires which are not Sn-plated, Ni-plated, Cu clad steel or Cu clad Al and alloyed. Do not use burnt wires for the brittleness.

2) Kanal or birch. This kind of scarp copper is composed of non-alloyed copper wires whose copper content is 96 %. They are the copper wires or brass and bronze wires without Pb-, Sn- and solder-plates. They also don't have ash content.

3) Grade 3 scarp copper (birch and candy). This kind of scrap copper consists of small-diameter, uninsulated copper wires which are usually used as telephone wires and clean, small- or large-diameter copper pipes.

4) Granular copper (clove). This kind of scarp copper is uninsulated copper wires. Uncovered non-alloyed scarp copper wire granular don't contain Sn, Pb, Al or Fe and the minimum copper content is

99 %.

5) Grade 3 scrap copper (dream). This kind of scarp copper is usually the mixture of non-alloyed scarp copper whose copper content is 92 %. It is composed of copper sheets, steam pipes, rainspouts, water heaters and other similar scarp copper. It should not contain insulators, refrigerators, radiators, shields, scrap copper with many Pb-, Sn- and solder-plates and oil.

To get the best result, it is suggested that the melting furnace materials abide by the following ratio: first-class scarp copper 30 %, second-class scarp copper 60 %, granular copper (clove) and third-class scarp copper 10 %.

The main impurities found in scarp copper are Pb, Sn, Zn, Fe, Ni, Al, Sb, S and Ag (Table 8). Little Bi, Te, Cr and Ag are also can be found.

Table 8 Average content of the main impurities in scarp copper

Element	Super-grade and grade 1 granular scrap copper	Grade 1 scrap copper	Granular copper	"Kanal" or "Birch" or grade 2 scrap copper	Grade 3 scrap copper and granular copper with high impurity content
	ppm				
Pb	≤5	<100	<500	<1 000	<5 000
Sn	≤4	<300	<100	<800	<9 000
Ni	≤4	<50	<150	<150	<3 000
Zn	≤25	<50	<200	<300	<12 000
Sb	≤2	<20	<50	<100	<1 000
S	≤15	<15	<100	<200	<800
Al	≤5	<50	<40	<200	<1 000
Fe	≤25	<50	<200	<500	<1 000
Ag	≤1	<50	<50	<50	<500
Average of melt loss	≤1.0 %	<2.0 %	≤2.0 %	<2.5 %	≤2 % ~ 8 %

2.4.2 Melting furnace and high-temperature processing technology

Sometimes, it is difficult to remove impurities, such as Pb, Sn, Ni, etc., and then it is necessary to process secondary refining to completely remove impurities. Special flux can be added into furnace to refine completely. The compare of impurities before and after refining are shown in Table 9. The contents of other impurities can be reduced to less than 5 ppm after refining. Because of the impurities' relative amount and variety, every furnace melt has its particularity. Therefore, the refining technology of every furnace has to be adjusted to fit content requirement of the melt.

Table 9 Impurities before and after refining of near-standard melt

Impurities	Before refining /ppm	After refining /ppm
Pb	400 ~ 700	70 ~ 90
Sn	150 ~ 300	50 ~ 60
Ni	80 ~ 100	50
Zn	60 ~ 80	< 10
Fe	50 ~ 80	< 10

2.4.3 Characteristics of the copper rods made directly from scarp copper

The characteristics of the copper rods made directly from scrap copper are shown in Table 10.

Table 10 Characteristics of the copper rods

Rod characteristics	Characteristics of the copper rods		Outcome
	Rod made from scrap copper	Rod made from electrolytic copper	
Chemical composition/%	(Cu + Ag) \approx 99.90	(Cu + Ag) \approx 99.95	The requirements of GB/T 3952, related wire and cable standards, ASTM B49 and ISO 1553 can be satisfied
Impurity/ $\times 10^{-6}$	700	150	
Oxygen/ $\times 10^{-6}$	200 ~ 350	200 ~ 350	
Elongation A100 %	40 ~ 45	45 ~ 50	
Elongation A200 %	35 ~ 40	40 ~ 45	
Tensile strength/(kgf \cdot mm $^{-2}$)	23 ~ 24	22 ~ 24	
Conductivity/% IACS	100 ~ 101	100 ~ 102	
Torsion test until failure/N	40 ~ 45	45 ~ 55	
Temperature of re-crystalline/ $^{\circ}$ C	300 ~ 325	250 ~ 275	
The pops test on oxidized layer/ 10^{-10} m	< 1 000	< 1 000	
Drawability/mm	0.3	\leq 0.05	

Note: 1 kgf \cdot mm $^{-2}$ = 9.80665 N

2.5 Some suggestions

1) Cooperation between the metallurgical industry and cable industry to give full play to one's own advantages in order to establish a model industrial area or plant for making rod directly from scrap copper.

2) For the industry for making rod directly from scrap copper, the technical reform, advancement in science and technology and technical upgrading shall be quickened, the grade of products shall be raised and discharge of pollutant shall be lowered so that the Industry of the copper rod made directly from scarp may develop healthily and steadily.

3) The parties concerned shall be coordinated and organized to carry out R & D of the technology and equipment for pre-treatment, smelting and wastes treatment for making rod directly from scrap copper so that the Industry may be promoted to a higher level.

4) The policy, regulation and standard concerning making rod directly from scrap copper shall be established. The scientific management of the manufacturing plants shall be improved and training of technical people quickened.

5) Never to underestimate the quality monitoring during the manufacturing process. The quality shall be always under control.

3 Saving copper with aluminum in the Chinese cable industry

As the rapid increase of copper price, the cable industry pays attention to save copper with aluminum. The price, raw material, production and market of aluminum are much better than copper. After the long-term effort of the cable industry, the electric aluminum rod production technology greatly improved. The elec-

tric aluminum rods can be made from the common-grade aluminum ingot whose aluminum content is 99.7 % by Rear-earth Optimization Comprehensive Treatment Technology, which was created by Shanghai Electric Cable Research Institute in 1980s. The technology has been widely adopted in Chinese cable industries. It fits for our country's condition with high Si of aluminum resources and provides material support for the expansion application of Chinese electric aluminum conductors.

Saving copper with aluminum in Chinese cable industry has been the main trend, because it clearly influences the cost and profit of wire and cable products^[15]. Besides, there are not many copper resources in China. But what extent saving copper with aluminum can develop into depends on the technical and economic feasibility and the agreement of suppliers and buyers. The saving copper with aluminum now is absolutely not the policy of using aluminum to replace copper which was advocated in 1960s to 1970s. At that time, copper was viewed as a defense material and it is very difficult to import copper because of the blockade. But the meaning of saving copper with aluminum now is to use copper when necessary and use aluminum when both copper and aluminum are acceptable. In the 20th century, many wire and cable products of use aluminum and aluminum alloy conductors are developed in and outside China. Once, the consumption of aluminum power cables and the consumption of copper power cables were almost the same.

Aluminum, aluminum alloy and bimetallic conductors have been applied to some wires and cables, especially the overhead conductors. At present, the application ratio of copper and aluminum conductors in

power cables has not greatly changed. There are many technical and economic difficulties to replace the copper winding wires in electric motors and transformers with aluminum and aluminum alloy wires. Small and medium electric motor industry has refused to use aluminum winding wires. It is predicated that the aluminum conductor consumed by middle voltage power cables will increase in foreign countries, while the aluminum conductor low voltage power cables will be more than middle voltage electric cables in China.

The conductors in wire and cable contributing to copper-saving include aluminum and aluminum alloy conductors, copper-clad-aluminum-conductor, copper-clad-steel-conductor, fine aluminum wire and copper-clad-aluminum-busbar.

3.1 Copper-clad-aluminum wire

Copper-clad-aluminum wire was developed in 1960s to 1970s in foreign countries. It is mainly used in the high frequency and radio frequency communication system^[16]. The wire and cable products in which copper-clad aluminum wire is or will probably be used and the consumption of copper-clad-aluminum wire and shares of the individual wire and cable products in China in 2006 are respectively shown in Table 11 and Table 12. The total consumption of copper-clad-aluminum wire in China in 2006 is 5×10^4 t, and most of them are used as communications wires and cables.

Table 11 Wire and cable products in which copper-clad aluminum is or will possibly be used

Application	Products in which copper-clad aluminum is or will possibly be used
Communications cables	Inner conductor in the branched to RF coaxial cables, conductors in local communication cable, braiding wire of braided shield, and tubular coated wire for mobile phone base station
Power cable and installation wire and cable	Conductors in power cable, installation wire and cable and building wire, braiding wire of braided shield in control cables
Automotive wire and cable	Battery wire, electronic wire, power wire for rear window defogger and power and communication wires in harness (including copper-clad-steel-wire)
Enamel wire	Microphone wire, computer wire and special silver-plated copper-clad-aluminum enamel wire
Electronic wires	Lead to resistor and capacitor
Profile for electrical switches	Copper-clad-aluminum-busbar
Overhead conductors	Copper-clad-aluminum-wire and copper-clad-steel core stranded overhead conductor

Table 12 Consumption of copper-clad-aluminum-wire and shares of the individual wire and cable products in China in 2006

Total consumption of copper-clad-aluminum-wire / 10^4 t	Shares of the individual wire and cable products/ (10^4 t/%)		
	Communications wire and cable	Power cables, installation wire and cable and enamel wires	Exports of copper-clad-aluminum-wire
5.0	2.5/50	1.5/30	1.0/20

Note: 1) The consumption of copper-clad-aluminum-wire by power cables amounted to 0.3×10^4 t in 2006 and is expected to be 0.6×10^4 t in 2007;

2) The total consumption of copper-clad-aluminum-wire is expected to be 7.5×10^4 t in 2007;

3) The exports of copper-clad-aluminum-wire are used mainly in communications wire and cable.

In high frequency and radio frequency, the application of copper-clad-aluminum wire in weak current has its obvious advantages. But there are some different opinions about its application in strong current. Copper-clad-aluminum wire has the characteristics of copper and aluminum; its electric conductivity, mechanical property and softness are lower than copper, but higher than aluminum; its weight is about 1/3 of copper; the production cost is lower than copper; anti-corrosion and connecting method are the same as copper. But compared with copper, clients usually have some unnecessary worries:

1) The temperature problem in long-term use. On the contact surface of copper and aluminum, CuAl_2 will generate in high temperature which is with brittleness and will affect the wire's processing ability and finished wire's elongation and conductivity. Therefore, the copper-clad-aluminum wire's long-term use temperature should be below 250°C , which is the with nickel-plated-copper core high temperature insulating aviation cable.

2) The connecting problem of copper-clad-aluminum wire. The connecting method of copper-clad-aluminum wire is the same with copper, and more convenient than aluminum. Adopt low temperature (below 250°C) solder when welding and copper-clad-aluminum stranded conductor can be crimp-press welded (Fig. 1). As for the problem whether the connector of copper-clad-aluminum power cable can pass the 1 000 thermal circulation test, suppliers and buyers can check this problem in GB 9327.4—88 Thermal Circulation Test Standard.

3) The problem of different heat expansion coefficients of copper and aluminum in copper-clad-aluminum wire. Actually, the problem of different heat expansion coefficients involves the problem of bonding

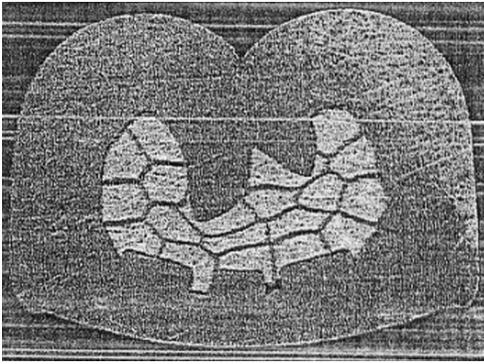


Fig. 1 Crimp-press-welded cross-section of a 0.82 mm² 19-strands copper-clad-aluminum stranded conductor cable

level of copper and aluminum. If copper and aluminum cannot be firmly bonded, the wire will not pass the drawing dies (affected by deformed forces and temperature). There is firm metallurgical bonding of copper and aluminum in copper-clad-aluminum wire (different from copper-plated aluminum wire). Therefore, the copper and aluminum in copper-clad-aluminum wire will not separate in the long-term use below 250 °C because of different heat expansion coefficients.

4) The problem of the copper cladding thickness uniformity of copper-clad-aluminum wire. Copper-clad-aluminum wire is a bimetallic wire made by cladding uniform copper strip on aluminum rods with two different metals' synchronous deformation and concentric drawing. Therefore, the concentricity and copper cladding thickness uniformity of the wire are very good, which are quite different from copper-plated aluminum wire.

5) The copper recovery problem of copper-clad-aluminum wire. The copper in copper-clad-aluminum wire can be recovered by either liquidating specific gravity separation or chemical method. Liquidating will loss part of pure copper and get Cu-Al alloy, which has to be used for other purposes or recovered. At present, there aren't many copper-clad-aluminum wires being used in China, while there are copper-clad-aluminum wires in the scrap copper from foreign countries. It is worthy researching on how to pick out copper-clad-aluminum wire to process recovery treatment, classification, grading and melting. The research is also significant, because if there is much aluminum in copper liquid, the quality of copper rods made directly from scrap copper will be affected.

In a word, it is important to take the security importance, installation reliability and economical efficiency into consideration according to the application of cable products when choosing conductor's materials. It depends on clients to use copper, copper-clad alumi-

num or electric aluminum conductor.

3.2 Copper-clad-aluminum busbar

Copper-clad-aluminum busbar is an electric material of switching equipment, which has its market in China. As the size of its section is comparatively large and it involves in many heavy equipment, it hasn't been produced domestically.

3.3 Copper-clad-steel wire

Copper-clad-steel-conductor is a product of saving copper with steel. It is a bimetallic wire made by cladding copper on steel with the metallurgical bonding of copper and steel. The production history of copper-clad-steel wire is longer than copper-clad-aluminum wire. Both of them are widely used in the fields of high frequency and radio frequency communications. There is a competition between them. Copper-clad-steel-wire is also widely used in ground-wire nets. This year, aiming at the overhead transmission line in high corrosion areas, some unit in China developed high corrosion-proof and high strength copper-clad-steel and copper-clad-aluminum stranded overhead conductor to replace copper stranded conductor and corrosion-proof ACSR. The electricity conductivity, corrosion-proof and strength of copper-clad-steel and copper-clad-aluminum stranded overhead conductor are better than ACSR. It is a kind of bimetallic composed conductor. Copper-clad-steel core combines the high strength of steel and the conductivity and corrosion-proof of copper, so it has high corrosion-proof and strong current carrying capacity. The conductivity, corrosion-proof and strength of copper-clad-aluminum wire are better than aluminum wire and its comprehensive performance is between aluminum and copper. Taking JTBL/TB 30 - 300/20 conductor as an example to be compared with 195 mm² copper stranded conductor direct current resistance, it is found that the weight decreases about 25 % per unit length and the total cost reduces 40 % per unit length when the copper weight ratio in raw material is 38 %.

3.4 Fine aluminum wires for the electrical application

Fine aluminum wires used as conductors mainly include Al-Mg alloy wires used as screened braided cables, Al-Mg-Si alloy wire which is the rival of copper-clad-aluminum wire in the field of screened braid and aluminum wires used for making enamel aluminum wires. As the diameters of fine aluminum wires are usually small, it is difficult to drawing them. International Electrician Committee (IEC) once formulated an enamel aluminum wires standard. But there hasn't any enamel aluminum wires standard in Chinese cable industry. It seems necessary to formulate this standard

from the point of development. The consumption of fine aluminum wires and shares of the individual wire and cable products in 2006 are shown in Table 13. The

output of the fine aluminum wires in China increases fast and it is 5×10^4 t in 2006 and most of them are exported to the countries in Southeast Asia.

Table 13 Consumption of fine aluminum wires and shares of the individual wire and cable products in 2006

Total consumption of fine aluminum wires by wire and cable/ 10^4 t	Al-Mg alloy wire for braided shield		Aluminum wires used in enamel aluminum wire	
	10^4 t /%	Application	10^4 t /%	Application
5.0	3.0/60	Braided shield in communications, control and shipboard cables and braided sheath for daily-life	2.0/40	HV transformer in microwave device, reactance, motor, micro-motor, demagnetization coil in TV set, lighting rectifier, computer monitor, kitchen motor, automotive wire and microphone

4 Conclusions

1) China is still in the initial stage of making copper rods directly from scrap copper. The support from the government policy as well as the coordinated technical supports from related parties are required to solve the problems arisen in the development of this Industry. A model industrial area for making rod directly from scrap copper jointly supported by the metallurgical industry and cable industry is proposed so as to accumulate experiences and popularize this technology nationwide.

2) It prospects well to research into the technique for direct recovery of scrap copper and to design the recovery facilities. Our entrepreneurs shall constantly strive to become stronger and be self-disciplined in terms of product quality.

3) The practice of saving copper with aluminum in the cable industry is an irresistible trend in China where copper is in short supply and the copper price is soaring. But we shall be realistic as to what lengths it will go. The industry of saving copper with aluminum can develop only when it is economically and technically feasible and this feasibility is recognized by both the buyer and supplier.

References

- [1] Huang Chongqi. Metal Conductors and Its Applications [M]. Shanghai; Shanghai Electric Research Institute, 2007.
- [2] Huang Chongqi. Cable Metal Collection [M]. Shanghai; Shanghai Electric Research Institute, 2001.
- [3] Huang Chongqi. The characteristics of electrical copper wires and the countermeasures to improve the quality of copper wires [A]. The 2007 Wire and Cable Forum [C]. Shanghai; Shanghai Electric Research Institute, 2007.
- [4] Huang Chongqi. The development of copper conductor processing technology [J]. Copper Processing Research, 2007, 4:1-5.
- [5] Zhang Xizhong. The opportunity, problem and development of recovered copper [A]. The Collection of the 3rd International Metal Recovery Market and Technology Forum [C]. Dalian; China Iron and Steel Association, China Non-ferrous Metals Industry Association, 2006.
- [6] Huang Chongqi. The chain reaction of cable industry caused by the rapid increase of copper price [A]. The Collection of 2007 Copper and Copper Material Summit Forum [C]. Qingdao; CBI (Shanghai) Co. Ltd., 2007.
- [7] Huang Xiaoming. Over 30 % wires and cables have hidden trouble in Hunan [J]. Wire and Cable Information, 2006, 6:31.
- [8] Huang Xiaoming. Over 60 % wires and cables are not qualified in Zhejiang [J]. Wire and Cable Information, 2006, 4:31-32.
- [9] Peng Bo. The most dangerous Guangdong cables—80 % products are unqualified [J]. The Recovery and Use of Non-ferrous Metal, 2006, 4:46.
- [10] Wang Gongmin. The copper industry development situation in and outside China and Chinese copper industrial policy [A]. 2007 Copper and Aluminum Summit Meeting—Resource, Price and Market [C]. Shanghai; Shanghai Non-ferrous Metals Industry Association, 2007.
- [11] Zhong Wenquan, Wang Yungang. The method of using scarp copper directly [J]. Resource Recovery, 2007, 3:16 - 19.
- [12] GB/T 3592 - 2008, The Standard of Electrical Copper Wire Stock [S].
- [13] GB/T 13587, The Classification and Technical Condition of Scrap Copper and Scrap Copper Alloy [S].
- [14] Huang Chongqi. The four concerns of Chinese cable industry to copper, rods and wires making [J]. Chinese Copper Industry, 2005, 1:20-30.
- [15] Mao Qingchuan, Yin Yongfu, Huang Haoshi. The application and development of metal conductors and wire products in Chinese cable industry [A]. The Report Collection of 2004 Chinese Cable Industry [C]. Shanghai; Shanghai Electric Research Institute, 2004.
- [16] Huai Ping, Cheng Qisong. The design and manufacture of copper-clad-aluminum communication cable [J]. Wire and Cable, 2007, 2:19-22.

(cont. on p. 36)