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Gallium-based liquid metal

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(*English Translation*)

(预审稿)

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Foreword

SAC/TC 243 is in charge of this English translation. In case of any doubt about the contents of English translation, the Chinese original shall be considered authoritative.

This document is drafted in accordance with the rules given in the GB/T 1.1—2020 *Directives for standardization—Part 1: Rules for the structure and drafting of standardizing documents*.

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This document was proposed by China Nonferrous Metals Industry Association.

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Gallium-based liquid metal

1 Scope

This document specifies the technical requirements, test methods, inspection rules, sign, packaging, transportation, storage, accompanying files, and the content of purchase order for gallium-based liquid metals.

This document is applicable to gallium-based liquid metals used as heat-transferring fluids, electrical conducting fluids, thermal interface materials, electronic paste, and magnetic fluids.

2 Normative references

The content in the following documents constitutes indispensable provisions/requirements in this document through normative references.

For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

GB/T 8170, *Rules of rounding off for numerical values & expression and judgment of limiting values*

GB/T 10247, *Methods of viscosity measurement*

GB/T 22588, *Determination of thermal diffusivity or thermal conductivity by the flash method*

SY/T 5370, *Test method for surface tension and interfacial tension*

YS/T 1256, *Nonferrous metal materials—Specific heat capacity testing—Differential scanning calorimetry*

YS/T 1257, *Nonferrous metal materials—Enthalpies of fusion and crystallization testing—Differential scanning calorimetry*

YS/T 1258, *Nonferrous metal materials—Melting and crystallization temperatures—Thermal analysis*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1

melting temperature

T_m

minimum temperature at which an alloy changes from solid state to liquid state of different viscosity

Note: in Celsius degrees (℃)

3.2

gallium-based liquid metal

alloys with gallium as matrix metal and melting temperature (T_m) less than 30 ℃

4 Technical requirements

4.1 Classification

The products are classified into 5 models according to the melting temperature, as shown in Table 1.

Table 1 – Product classification

Product model	Melting temperature (T_m) ℃	Typical proportioning
LMG-1	< 9	Ga-25In-13Sn-1Zn
LMG-2	9≤ T_m < 14	Ga-22In-16Sn，Ga-29In-4Zn
LMG-3	14≤ T_m < 18	Ga-24.5In
LMG-4	18≤ T_m < 24	Ga-14Sn
LMG-5	24≤ T_m < 30	Ga-4Zn

4.2 Appearance quality

The product is silver-white liquid, or light gray paste-like solid-liquid mixture, or light gray solid. The surface of the product shall be clean and of metal luster, and there shall be no obvious color difference, as well as foreign matter such as dust and oil.

4.3 Physical properties

4.3.1 The melting temperature of the product shall comply with the specifications provided in Table 1; the thermal conductivity and electrical conductivity shall comply with the specifications provided in Table 2.

Table 2—Thermal conductivity and electrical conductivity of product

Product model	Thermal conductivity W/(m·K)	Electrical conductivity 10^6 S/m
LMG-1	≥20	≥3.00

LMG-2	≥20	
LMG-3	≥25	
LMG-4	≥25	
LMG-5	≥25	

4.3.2 The following physical parameters of the product shall be indicated in the purchase order after negotiation and confirmation by the supplier and the buyer:

a) density;

b) surface tension;

c) viscosity;

d) specific heat capacity;

e) enthalpy of melting.

5 Test methods

5.1 Appearance quality

Appearance quality shall be inspected visually.

5.2 Physical properties

5.2.1 The determination of melting temperature shall conform to the provisions in YS/T 1258.

5.2.2 The determination of thermal conductivity shall conform to the provisions in GB/T 22588.

5.2.3 The determination of electrical conductivity shall conform to the provisions in Annex A.

5.2.4 The determination of density shall conform to the provisions in Annex B.

5.2.5 The determination of surface tension shall conform to the provisions of the pendant-drop method as specified in SY/T 5370.

5.2.6 The determination of viscosity shall conform to the provisions of the rotation method as specified in GB/T 10247.

5.2.7 The determination of specific heat capacity shall conform to the provisions in YS/T 1256.

5.2.8 The determination of enthalpy of melting shall conform to the provisions in YS/T 1257.

6 Inspection rules

6.1 Inspection and acceptance

6.1.1 The product shall be inspected by the quality department of the supplier to ensure that the product conforms to the provisions of this document and the purchase order, and the accompanying documents shall be filled out.

6.1.2 The buyer may inspect the received products according to the provisions of this document. Where the inspection results do not conform to the provisions of this document and the purchase order, the non-conforming products shall be sealed separately and reported to the supplier in writing within 30 days from the date of receipt of the product or within the time specified in the sales contract, which should be settled by the supplier and the buyer through negotiation. If arbitration is required, arbitration sampling shall be carried out jointly by both the supplier and the buyer in the products received by the buyer.

6.2 **Batching**

Products shall be submitted for acceptance in batches. Each batch shall consist of products from the same smelting furnace and the same type. The total amount of each batch shall not exceed 200 kg.

6.3 **Sampling**

Randomly take 5% of the number of bottles from each batch of products (not less than 5 bottles; where the batch is less than 5 bottles, take all); take 5 g ~ 25 g from each bottle; mix them evenly.

6.4 **Inspection items**

Each batch of products shall be inspected for appearance quality and physical properties according to the requirements of Chapter 4 and the test methods of Chapter 5.

6.5 **Inspection results judgement**

6.5.1 If the inspection result of appearance quality is unqualified, the batch of products shall be judged as unqualified.

6.5.2 If any of the inspection result of the melting temperature, thermal conductivity, and electrical conductivity is unqualified, a double number of samples shall be taken from this batch of products for a repeated test. If the inspection result is still unqualified in the repeated test, the batch of products shall be judged as unqualified.

6.5.3 The inspection results judgement of density, surface tension, viscosity, specific heat capacity, and enthalpy of melting shall be negotiated by both the supplier and the buyer and shall be indicated in the purchase order.

7 Sign, packaging, transport, storage, and accompanying documents

7.1 Sign

7.1.1 Inner package sign

The following signs (or labels) shall be printed on the inner package of qualified products:

a) product name;

b) supplier name;

c) product model;

d) net weight;

e) metal corrosion warning labels;

f) batch number;

g) shelf life;

h) production date;

i) reference to this document (GB/T 39859).

7.1.2 Outer package sign

The following signs shall be printed on the outer package of qualified products:

a) product name;

b) supplier name;

c) batch number;

d) quantity;

e) outer box size;

f) production date;

g) signs such as no-pressure and no-tilt.

7.2 Packaging

7.2.1 Inner package

The product comes in a single package. The product shall, after melting, be filled into bottles made of plastics such as polypropylene. The net weight of product in each bottle shall not exceed 1 kg. The packaged bottles shall be filled with inert gas or vacuum sealed. If the buyer has any special requirement, it shall be indicated in the purchase order after negotiation and confirmation between the supplier and the buyer.

7.2.2 Outer package

The outer packaging of the product shall be firm and meet the requirements of anti-pressure, shock-proof, and moisture-proof.

7.3 Transportation

During transportation of the product, squeezing, inversion, sun exposure, rain, or collision shall be avoided.

7.4 **Storage**

The product shall be stored in a well-ventilated, dry storage room where the ambient temperature is 0 ℃ ~ 40 ℃ and the relative humidity is not more than 70%. There shall be no corrosive gases such as acid and alkali in the room. The packaging box shall be elevated, at least 20 cm above the ground, and at least 50 cm away from walls, heating equipment or air conditioning equipment.

7.5 **Accompanying documents**

Each batch of product shall be attached by accompanying documents, which shall include supplier information, product information, reference to this document (GB/T 39859), date of manufacture or packaging date, and should also include:

a) Product quality assurance certificate:

- Main performance and technical parameters of the product;
- Product features (including the features of manufacturing process and raw materials);
- Responsibility for product quality;
- Quality certification obtained by the product and the inspection results with seal of the supplier's technical supervision department.

b) Certificate of conformity:

- Inspection items and their results, for non-factory inspection items the test results of the latest type inspection shall be indicated;
- Batch size or batch number;
- Date of inspection;

- Inspector's signature or seal.

c) Inspection reports during product quality control and inspection report of finished product;

d) Product instructions: proper handling, use, and storage methods, etc.;

e) Others.

8 **Content of purchase order**

The purchase order for the products listed in this document shall contain the following:

a) Product name;

b) Product model;

c) Quantity;

d) Packaging method;

e) Special requirements shall be negotiated by both the supplier and the buyer as specified in this document;

f) Reference to this document (GB/T 39859).

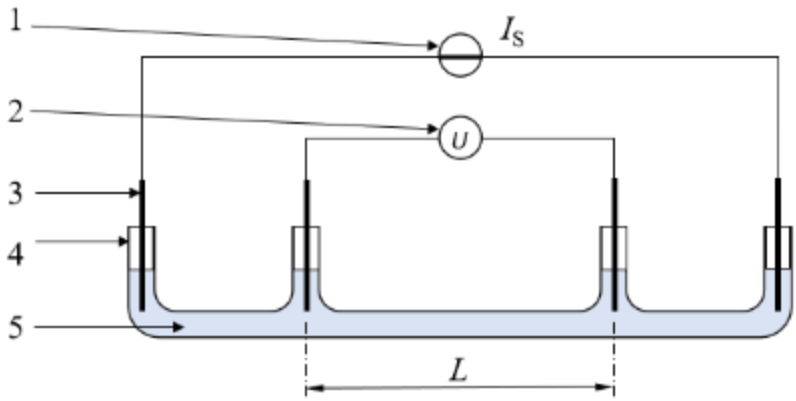
Annex A

(**normative**)

Method for determination of electrical conductivity

A.1 **Principle**

A DC four-point probe method is used to measure the electrical conductivity based on the principle of Ohm's law. As shown in Figure A.1, by measuring the voltage drop of the liquid metal in a quartz tube of known length and cross-sectional area under a constant current, the electrical resistance and conductivity of the liquid metal are calculated.



Key:

1—constant-current power supply;

2—digital voltmeter;

3—probe;

4—conductivity cell;

5—sample;

L—length of the sample between the voltages probes.

Figure A.1—Schematic diagram of the principle of measuring conductivity of liquid metal by the DC four-point probe method

A.2 **Apparatuses**

A.2.1 **Constant-current power supply,** being able to provide direct current of 1 mA ~ 1 000 mA. During measurement, the constant current is known and the fluctuation range does not exceed ±0.5%.

A.2.2 **Digital voltmeter,** being able to measure the voltage of 0.01 mV ~ 100 mV with measurement error less than ±0.5%. The input impedance of the instrument shall be 3 orders or more of magnitude greater than the resistance of the sample.

A.2.3 **Probes,** being not able to dissolve in or react with the sample. The probes may be made of graphite, tungsten, molybdenum, etc.

A.2.4 **Conductivity cell,** being in accordance with the structure in Figure A.1, with the ratio of the cross-sectional area of the quartz container between the voltage probes to the length of the sample not greater than 0.2 mm.

A.2.5 **Constant-temperature bath.** Water bath or oil bath, where the temperature error at constant temperature should not exceed ±0.5 ℃.

A.2.6 Other fixtures and spreaders for the conductivity cell and probes.

A.3 **Test temperature**

The test temperature shall be in the range of 25 ℃ ~ 30 ℃, not lower than the melting temperature of the sample, and indicated in the test report.

A.4 **Test procedures**

A.4.1 Set the temperature of the constant-temperature bath to the test temperature; fix the conductivity cell in the bath.

A.4.2 Load the liquid metal sample into the conductivity cell; fix the four probes connected to the constant current power supply and the digital voltmeter at the preset positions according to Figure A.1. The height of the sample liquid level shall ensure that the tip of the probe is not less than 0.5 cm immersed in the sample.

A.4.3 Start the constant current power supply to apply a constant direct current through the sample; read after the indication of the voltmeter is stable; record the voltage between the two voltage probes.

A.5 **Test data processing**

A.5.1 **Calculation of resistivity**

A.5.1.1 The resistivity of the sample is calculated from Formula (A.1):

$$r = \frac{S}{L}\frac{\Delta U}{I} \qquad \text{..... (A.1)}$$

where:

r —resistivity, expressed in ohm-meter (Ω·m);

S —cross-sectional area of the sample between the voltage probes, expressed in square meter (m^2);

ΔU—voltage between the voltage probes, expressed in volt (V);

L —length of the sample between the voltage probes, expressed in meter (m);

I —constant current passing between the current probes, expressed in ampere (A).

Reserve three significant figures for the calculation result. Carry out rounding of the numerical value according to the provisions of GB/T 8170.

A.5.1.2 The resistivity of the sample can also be calculated from Formula (A.2):

$$r=C\frac{\Delta U}{I} \qquad \text{.....(A.2)}$$

C —conductivity cell constant calibrated with standard samples, expressed in meter (m).

Reserve three significant figures for the calculation result. Carry out rounding of the numerical value according to the provisions of GB/T 8170.

A.5.2 **Calculation of conductivity**

The conductivity of the sample is calculated from Formula (A.3):

$$\sigma=\frac{1}{r} \qquad \text{..... (A.3)}$$

where:

σ —conductivity of the sample, expressed in Siemens per meter (S/m).

Reserve three significant figures for the calculation result; carry out rounding of the numerical value according to the provisions of GB/T 8170.

Annex B

(normative)

Method for determination of density

A.1 Principle

A hydrostatic weighing method is used for the determination of density according to Archimedes' principle. The mass and volume of the liquid metal sample are measured by weighing in air as well as in pure water. The density of the sample is then calculated.

A.2 Apparatuses

A.2.1 **Balance,** with division value of 0.000 1 g.

A.2.2 **Sample cup.** An open container made of quartz is recommended.

A.2.3 **Thermometer.** A mercury thermometer, of which the minimum division value is 0.1 ℃ and the range can meet the measurement requirements, should be used.

A.2.4 **Pure water preparation device,** available for manufacturing laboratory grade-2 water.

A.2.5 **Spreader,** applicable to weighing samples of different masses in water.

A.2.6 Other proper holder for balances, water cup, and dryer.

A.3 Sample

The sample shall be no less than 2 mL and not react with water.

A.4 **Test temperature**

The test temperature shall be in the range of 20 ℃ ~ 30 ℃, not lower than the melting temperature of the sample, and indicated in the test report.

A.5 **Test procedures**

A.5.1 Let the sample, pure water and test equipment stand still at the test temperature for not less than 1 h.

A.5.2 Weigh the mass (m) of the empty sample cup in air.

A.5.3 Put the empty sample cup on the spreader and immerse it completely in water; weigh the mass (m_1).

A.5.4 After the sample cup is completely dried, load the liquid metal sample into the sample cup; weigh the mass (M) in air.

A.5.5 Place the sample cup containing liquid metal on the spreader and immerse it completely in water; weigh the mass (M_1).

A.5.6 The water temperature may be the average value of the two measured temperatures before and after weighing in water.

A.6 **Test data processing**

The density of the sample is calculated from Formula (B.1):

$$\rho = (M - m)\rho_t / \left[(M - m) - (M_1 - m_1)\right] \quad \text{.....(B.1)}$$

where:

ρ —density of the sample, expressed in gram per cubic centimeter (g/cm^3);

M —mass of the sample and sample cup weighed in air, expressed in gram (g);

m —mass of the sample cup weighed in air, expressed in gram (g);

ρ_t —density of water at temperature t, expressed in gram per cubic centimeter (g/cm^3), which can be found in Table B.1;

M_1—mass of the sample and sample cup weighed on the spreader in water, expressed in gram (g);

m_1 —mass of the sample cup weighed on the spreader in water, expressed in gram (g).

Reserve three significant figures for the calculation result; carry out rounding of the numerical value according to the provisions of GB/T 8170.

Table B.1—Density of pure water

in gram per cubic centimeter

t	0.0 ℃	0.1 ℃	0.2 ℃	0.3 ℃	0.4 ℃	0.5 ℃	0.6 ℃	0.7 ℃	0.8 ℃	0.9 ℃
20 ℃	0.998 203	0.998 182	0.998 162	0.998 141	0.998 120	0.998 099	0.998 077	0.998 056	0.998 035	0.998 013
21 ℃	0.997 991	0.997 970	0.997 948	0.997 926	0.997 904	0.997 882	0.997 859	0.997 837	0.997 815	0.997 792
22 ℃	0.997 769	0.997 747	0.997 724	0.997 701	0.997 678	0.997 655	0.997 631	0.997 608	0.997 584	0.997 561
23 ℃	0.997 537	0.997 513	0.997 490	0.997 466	0.997 442	0.997 417	0.997 393	0.997 396	0.997 344	0.997 320
24 ℃	0.997 295	0.997 270	0.997 246	0.997 221	0.997 195	0.997 170	0.997 145	0.997 120	0.997 094	0.997 069
25 ℃	0.997 043	0.997 018	0.996 992	0.996 966	0.996 940	0.996 914	0.996 888	0.996 861	0.996 835	0.996 809

26 ℃	0.996 782	0.996 755	0.996 729	0.996 702	0.996 675	0.996 648	0.996 621	0.996 594	0.996 566	0.996 539
27 ℃	0.996 511	0.996 484	0.996 456	0.996 428	0.996 401	0.996 373	0.996 344	0.996 316	0.996 288	0.996 260
28 ℃	0.996 231	0.996 203	0.996 174	0.996 146	0.996 117	0.996 088	0.996 059	0.996 030	0.996 001	0.995 972
29 ℃	0.995 943	0.995 913	0.995 884	0.995 854	0.995 825	0.995 795	0.995 765	0.995 753	0.995 705	0.995 675
30 ℃	0.995 645	0.995 615	0.995 584	0.995 554	0.995 523	0.995 493	0.995 462	0.995 431	0.995 401	0.995 370