Study on heat treatment and coating of copper screw female in friction pair of rock drill

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Abstract. Aiming at the copper screw female parts of the rock drill friction pair that are made of tin bronze and easy to wear, the material, hardness, the metallographic structure and other comparative studies have conducted in-depth research on the formation mechanism of the application of thermal spraying technology on the copper spiral female parts of the rock drill product. The copper spiral female in the friction pair of the rock drill after heat treatment and thermal spraying has been tested on site by the customer. With better results, it is hoped that it can be used as a reference for the study of other friction pairs in rock drill products.

1. Introduction

Pneumatic rock drill occupies a large share in the market of rock drilling machinery due to its low price. It is widely used in mining, railway and highway construction sites, and its working environment is generally in open air, pit or tunnel, etc [1]. The screw female is the most critical part of the rotary mechanism in pneumatic rock drill [2]. It is usually made of tin bronze, and its quality directly affects the service life of pneumatic rock drill. According to the field survey, the tin bronze screw female used by a certain type of pneumatic rock drill has a very low life, with a footage of only about 2000m, causing serious waste of scarce non-ferrous metals. Serious wear of the screw parent is bound to lead to serious wear of the matching screw rod, which will significantly reduce the drilling efficiency of pneumatic rock drill [3, 4].

Skalka P et al. [5] studied the effect of the waviness of the bond coat and the thickness of the thermally grown oxide (TGO) layer on the stability of plasma-sprayed thermal barrier coatings. Slámečka K et al. [6] based on the obtained results and experimental evidence from the literature, a role of the interfacial topography in the failure sequence is discussed for oxidized and thermally-cycled coatings. Yin Ao [7], Su X et al. [8] took tin bronze (QSn7-0.2) as the research object, and heat treated the high temperature extruded tin bronze at 200, 300, 400 and 500°C respectively. The results show that the grain size and microstructure distribution of tin bronze are more uniform after heat treatment and annealing at 350–450°C, and it has better hardness, strength and plasticity, which is more conducive to the subsequent processing process. Xiao H [9] studied the effects of heat treatment temperature on microstructure and mechanical properties of semi-solid extruded ZCuSn10P1 tin bronze. The optimal heat treatment process is 350°C for 120 min, at which the tensile strength, elongation and Brinell hardness of tin bronze are 402 MPa, 4.5% and 1360 MPa, respectively, which are increased by 3.88%, 60.71% and 6.25% compared with those before heat treatment.

Therefore, it is an urgent problem for pneumatic rock drill to improve the service life of screw female and make it consistent with the service life of screw rod. Female in this paper, the two manufacturers copper screw parts of contrast research, including material, hardness, microstructure of the thermal...
Spraying technique on the mother rock drill product copper screw parts then explores its formation mechanism research, the drill after heat treatment and thermal spraying of the friction pair copper screw female on customer site test, to reduce the spiral mother wear, improve its service life provides certain reference basis.

2. Copper screw base material and hardness analysis

The friction pair of copper nut (see figure 1) is the most important connecting transmission mechanism on pneumatic rock drill. The quality of copper screw base directly affects the service life of pneumatic rock drill.

![Figure 1. Copper nut friction pair.](image)

As tin bronze QSN7-0.2 (chemical composition and properties are shown in table 1) has the advantages of high strength, good wear resistance, good corrosion resistance, good cutting ability, etc., the copper screw female is usually made of tin bronze.

| Cu  | Sn  | Pb  | P   | Al  | Fe  | Si   | Sb   | Bi  | Tensile strength (MPa) | Elongation δ10 (%) |
|-----|-----|-----|-----|-----|-----|------|------|-----|------------------------|-------------------|
| 6.0~8.0 | ≤0.02 | ≤0.25 | ≤0.02 | ≤0.05 | ≤0.02 | ≤0.002 | ≤0.002 | ≤0.15 | ≥665 | ≥2 |

Abrasion resistance refers to the ability to resist friction. The factors affecting this ability are not only dependent on the composition, structure and properties of copper, such as hardness carbide characteristics, quantity, shape and distribution, but also closely related to the conditions of use and tensile process, such as the adhesion of a large number of sand ash layer on the surface of wire rod.

Soft matrix + hard point is an ideal wear-resistant material (see figure 2). In tin bronze, the matrix is phase (Sn replacement solid solution in Cu, with a face-centered cubic structure), which has excellent plasticity and is suitable for cold and hot machining deformation. The hard point (Cu₃Sn, complex cubic lattice structure) is hard and brittle, and only + phase is usually observed in the cast and annealed tin bronze tissues.

![Figure 2. Relationship between tin content and mechanical properties of cast Copper-tin alloy [10].](image)
Hardness is an important performance index to measure the degree of hardness of metal materials. It can be understood as the ability of material to resist elastic deformation, plastic deformation or failure, and can also be expressed as the ability of material to resist residual deformation and anti-failure. Under the same conditions (the same friction coefficient, composition, microstructure, environmental conditions, etc.), there is a nonlinear proportional relationship between hardness and wear resistance.

According to the field survey, the sites used are all iron ore. The footage of pneumatic drill products of A company and B company and the scrap standard of copper screw parent are shown in table 2. The material and hardness testing of copper screw parent of A Company, B company and C company are shown in table 3.

As can be seen from the above table, QSn7-0.2 tin bronze is selected as the spiral mother material for both company A and company B. The spiral mother hardness of company A is 195 HB, and that of company B is 124 HB.

Further research and improvement will be made on heat treatment and plasma thermal spraying of copper spiral mother of A company.

### Table 2. Field footage and scrap standard for copper screw female.

| Company | Working time | Working life (m) | Mode of action | Scraping standard | Measuring position |
|---------|--------------|------------------|----------------|-------------------|-------------------|
| A       | 30 shifts    | 1380             | 2.5 m drill rod, 20 holes per shift | Spline profile | Wear 2 mm |
| B       | 35 shifts    | 1610             |                |                   | Measure the width w of spline keyway at 18.5 mm of large end face, and discard it when w ≥ 7.4 mm |

### Table 3. Copper spiral parent material and hardness testing.

| Manufacturer | Cu    | Sn    | Pb    | P     | Ni    | Fe    | Si    | Ti    | Hardness (HB) | Material   |
|--------------|-------|-------|-------|-------|-------|-------|-------|-------|---------------|------------|
| A            | 91.01 | 7.28  | 0.2   | 0.1   | 0.6   | 0.2   | 0.1   | 195   | QSn7–0.2      |            |
| B            | 91.07 | 7.61  | 0.06  | 0.2   | 0.8   | 0.1   |       | 124   | QSn7–0.2      |            |
| C            | 89.53 | 9.17  | 0.1   | 0.2   | 0.21  | 0.2   | 0.3   | 184   | ZSn10         |            |

3. **Research on plasma thermal spraying**

Thermal spraying technology is through the flame, or plasma arc heat source, will be a linear or powdered material heated to melt or semi-molten state, and accelerate the formation of molten drop, high speed spray to form coating matrix, the properties of materials can be strengthened or regeneration, protection, and the components caused by corrosion or wear processing out-of-tolerance size reduced to repair. The surface of the material can also be given special properties.

Plasma spraying is a thermal spraying processing method in which rigid non-transfer plasma arc is used as heat source to heat the powder material to molten or semi-molten state and spray it to the surface of the pretreated workpiece through high-speed flame flow to form spray coating. Its principle is shown in figure 3.
In the process of coating formation, a single molten particle is the basic unit of coating formation, and its behavior reflects the characteristics of coating formation. The behavior of a single particle consists of three basic processes: first, the spraying material is sent to a heat source; then comes the interaction process between the spraying material and the heat source. Under the action of the heat source, the material is heated, melted and accelerated. At the same time, the interaction process between high temperature and high speed particles and the ambient atmosphere also occurs. Finally, the collision of high temperature and high speed molten particles with the matrix, horizontal flow flattening and rapid cooling solidification are discussed. The whole process is completed in a very short time of tens of microseconds.

The spray gun is actually a non-transfer arc generator, which is the most critical component. It concentrates the electricity, gas, powder and water of the whole system on the spray gun. The spray gun can be supplied with direct current by connecting to the power supply, which is usually a full-wave silicon rectifier. Spray gun can be replaced by nozzle and other parts to meet the requirements of spraying different materials. The spray gun is shown in figure 4. The top end of the spray gun is the powder conveying conduit, and the bottom end is the pipeline of cooling water and working gas. The powder feeder used is shown in figure 5.
4. Copper spiral mother heat treatment and coating

Copper spiral mother is the raw material of tin bronze QSn7-0.2 in the manufacturing process, through the process of thermal deformation. After the alloy was heated and extruded, the structure property of billet was the best, especially the section shrinkage rate. It can be found from the study that the high temperature extrusion of tin bronze by induction heating has good plasticity and strength. However, in the processing process of high temperature extrusion, the grain structure of tin bronze is not evenly distributed, and some grains grow up unusually, resulting in the unstable plastic performance of tin bronze and the potential safety hazard. In order to solve this problem, it can be annealed after warm extrusion to make its structure homogenize, reduce the internal stress and improve its plastic property, which is beneficial to the subsequent spinning and other processing technology, and has a certain effect on reducing the stress concentration and improving the surface smoothness.

Tin bronze alloy is mainly composed of copper, tin, nickel, lead and other elements. The diffusion process of tin in solid state in copper is very slow, and it is easy to form in-grain segregation and a small amount of 8-phase in as-cast state, and it can be eliminated only after homogenizing annealing at high temperature. Both, nickel and copper are plane-centered cubic structures, and the difference in atomic radius is very small. Therefore, nickel can dissolve in unbounded solid, but nickel diffuses slowly in copper, and it is easy to form significant dendritic structure. Lead does not dissolve in copper and is generally distributed in a free phase between the crystal branches. By analyzing the main components of the alloy, combining with the phase diagram, changing the distribution of the eutectoid between the dendritic crystals and the dendrites by means of heat treatment can obviously change the properties of the alloy. Through the comparison of the above test results, it can be seen that the peak performance index of the alloy between 350 ~ 450°C appears, indicating that the conductivity, hardness and tensile strength of the alloy have been effectively improved at this time. The test data after heat treatment annealing are shown in table 4.

Table 4. Annealing heat treatment data sheet.

| No. | Annealing temperature (°C) | Annealing time (min) | External hardness (HB) | Internal hardness (HB) | Tooth root hardness (HB) |
|-----|---------------------------|----------------------|------------------------|------------------------|-------------------------|
| A   | 370                       | 40                   | 179                    | 177                    | 172                     |
| B   | 370                       | 10                   | 139                    | 180                    | 152                     |
| C   | 250                       | 40                   | 182                    | 209                    | 202                     |
| D   | 400                       | 10                   | 116                    | 137                    | 120                     |

The metallographic structure after annealing is shown in figure 6. The structure is α phase + δ phase, the black dendritic axis is copper rich solid solution (α phase), the white is tin rich solid solution (δ phase), the grain size and microstructure are uniformly distributed, and a large number of equiaxial twins can be seen. This is because static recrystallization occurs in tin bronze with the increase of annealing temperature.

Figure 6. Spiral mother QSN7-0.2 annealed metallographic structure.
Hard alloy is an excellent tool material and structural material. At present, its production raw material is mainly nano-tungsten-Cobalt (WC-CO) composite powder. Tungsten carbide (WC) is a kind of hard alloy material with high hardness, thermal stability and good wear resistance. Tungsten carbide insoluble in water, hydrochloric acid and sulfuric acid, easy to dissolve in nitric acid - hydrofluoric acid mixed acid. Pure tungsten carbide is brittle and can reduce brittleness if a small amount of metals such as titanium and cobalt are added. Tungsten carbide used as steel cutting tools is often added with titanium carbide, tantalum carbide or a mixture of them to improve the anti-explosion ability, and its chemical properties are stable. The powder is shown in figure 7.

![Unsintered powder](image1) ![Sintered powder](image2)

**Figure 7.** Nanometer Tungsten-Cobalt (WC-CO) composite powder.

Copper screw parent is shown in figure 8.

![Copper screw before thermal spraying](image3) ![Copper screw after thermal spraying](image4)

**Figure 8.** Copper screw female.

After dealing with the annealing and thermal plasma spraying of copper screw female, with untreated copper screw female field test in some iron mine, test data as shown in table 5, can be seen from the table, after annealing and plasma thermal spraying, the copper screw female longevity by about 22.5%.

| Company | Mode of action | Working time | Working life (m) | Remarks |
|---------|----------------|--------------|-----------------|---------|
| A       | 2.5 m drill rod, 20 holes per shift | 31 shifts improvement | 1426 | before |
| A       | 38 shifts improvement | 1748 | after |
5. Conclusion
The results show that the structure of the alloy tends to be homogenized with the reasonable annealing system, and the performance index peaks, but the elongation after fracture decreases. Therefore, by selecting a reasonable heat treatment process for the new type tin-bearing copper casting, the conductivity, hardness, tensile strength and other properties of the material can be improved completely, the study can be extended to other friction pair of pneumatic rock drill products.

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