# DEVELOPMENT OF MATERIAL USED FOR AVIATION APPARATUS AXLE JOURNALS①

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**ABSTRACT** An advanced Co-25W alloy used for producing aviation apparatus axle journals and its technological processes were described. Because high-purity raw materials and consumable-electrode refine technology were used, the content of oxygen and other impurities in the alloy were reduced to 0.011 % and 0.5~1.0 grade respectively. So, the hot-working properties of the alloy was considerably improved. When deformation temperature and cross-section shrinkage ratio of each procedure including forging, hot-rolling, rotary forging and wire-drawing were well controlled, the alloy could be drawn into wire of 0.50 mm in diameter. Its Vickers hardness (Hv) of as-drawn alloy was 4500~5500 MPa, and it could be improved to more than 7200 MPa to meet the requirements of axle journals, which was ascribed to age pricipitated $Co_3W$ phase in vacuum or $H_2$ atmosphere. The optimum aging temperature was 650 ℃, aging time 8 h. By means of metallography and XRD, microstructure changes in the course of processing, many factors influencing the process properties of the alloy and their choice principles were discussed in details. The influences of aging temperature and time on hardness of Co-W alloy and the age-hardening mechanism were investigated.

**Key words** Co-25W alloy axle journals consumable-electrode melting wire-drawing age-hardening

## 1 INTRODUCTION

It is well-known that the vital part of aviation apparatus is composed of axle journals, jewels and balance springs. The bearing area between jewel and axle journal (0.50 mm in diameter and 4 mm long) is very small, however, the axle journal bears high static pressure, even up to 500 MPa when plane flies with a 80~90 $m/s^2$ acceleration. Therefore, the materials used for axle journals must be of high-hardness, high-strength, high elastic modulus, excellent wear-resistance and oxidation-resistance in order to work securely and stablely for the apparatus.

Although such materials as $T_{12}A$ high speed steel, $3J_{23}$ and Co40 have been used for axle journals of normal electical apparatus, an alloy wire with component of 75% Co and 25 % W is the first choice of material for sophisticated aviation apparatus axle journals. Genarally, the alloys containing cobalt 40% ~ 70% are called the cobalt base alloys. As the materials used in high-temperature condition, the alloys have been early utilized for aviation, e.g. making jet turbine[1]. Some cobalt base alloys containing 20% ~ 30% W can be used for coat and film according to their special properties, including optical, magnetic, electroplate, corrosion-resistance and wear-resistance[2, 3]. The Co-25W alloy possesses a series of excellent mechanical properties, so, it can be used for making apparatus axle journals; however, there is little information concerning its preparing process. An advanced Co-25W alloy wire with good toughness, uniform hardness and little amount of impurities, has been prepared to meet the requirements of aviation apparatus industry.

## 2 PREPRODUCTION PROCESS OF Co-25W ALLOY WIRE

Firstly, crude cobalt sheet and tungsten

① Project supported by the National Plan Committee Foundation of China Received Feb. 25, 1998; accepted Mar. 9, 1998

sliver were purified. The alloy was melted in a medium-frequency vaccum induction furnace, then the cast ingot was refined by a consumable-electrode vacuum furnace. Table 1 presents the chemical composition of raw materials and alloy.

**Table 1 Chemical composition of raw materials and alloy (mass fraction, %)**

| Designation | Co | W | Mn | C | O |
|---|---|---|---|---|---|
| Electrolytic cobalt sheet | ≥99.5 | – | – | – | – |
| Tungsten sliver | – | 99.8 | – | – | – |
| Electrolytic manganese slice | – | – | 99.9 | – | – |
| Spectral pure graphite rod | – | – | – | 99.99 | – |
| Vacuum melted cast ingot | 75.18 | 24.40 | 0.34 | 0.031 | 0.046 |
| Consumable-electrode remelted ingot | 74.67 | 24.99 | – | 0.024 | 0.011 |
| Requirements of axle journal material | 74~ 76 | 26~ 24 | – | – | – |

Owing to the low ductivity, high formability resistance, poor thermal conductivity and narrow temperature range of hot working of Co-W alloy, it is necessary to conduct such working procedures as hot forging, hot rolling, rotary rolling and wire-drawing to make the consumable remelted cast ingots ( *d*86 mm) deform into wires ( *d* 0.50 mm). The parameters of each procedure arelisted in Table 2.

## 3 RESULTS AND DISCUSSION

### 3.1 Melting

Co-W alloy can be prepared by means of powder metallurgy as well as melting. The process of P/M is simple, and the production ratio is high. However, the alloy is hard to be deformed, especially be wire-drawn because the cobalt and tungsten powder aren' t pure, the high content of oxygen and hydrogen in sintered alloy will form oxide impurities during this process. As a result, melting process was adopted for preparing Co-25W alloy.

By means of vacuum induction melting and consumable-electrode vacuum remelting, the harmful gas like $O_2$, $N_2$ and $H_2$ can be eliminated effectively, and crystallization morphology of the cast ingot is also improved. Table 1 shows that the oxygen content of the alloys is considerably reduced after consumable-electrode remelting. The temperature of vacuum induction melting was 1 600 ℃, vacuum 0.5 Pa, refining time 20 min, pouring temperature 1 500 ℃. During the course of consumable- electrode remelting, vacuum was 0.13 Pa, and consumable time 10~ 15 min.

Normally, the content grade of ductile and

**Table 2 Parameters of producing Co-W alloy wire**

| Procedure | Device | Temperature / ℃ | Times of each procedure | Cross-section shrinkage ratio/ % | Diameter / mm | Specification |
|---|---|---|---|---|---|---|
| Hot forging | 1t vapor hammer | 1 250~ 1 000 | 5 | From small to large | 86~ 43 | Hammering lightly |
| Hot rolling | Three-roll mill | 1 210~ 900 | 15 | 25~ 35 | 40~ 25~ 8.5 | Heating twice |
| Rotary rolling | Type 203 | 1 200 | 1 | 4.5 | 8.50~ 8.15 | |
| | Type 202 | 1 000~ 950 | 12 | 13.0~ 7.0 | 8.15~ 3.40 | |
| | Type 201 | 900~ 850 | 2 | 8.0 | 3.40~ 2.85 | |
| Wire-drawing | *d*1.2 m draw bench | 900 | 9 | 20~ 16 | 2.85~ 1.17 | |
| | *d*1.0 m draw bench | 850 | 7 | 16 | 1.17~ 0.90 | Annealing 1 time |
| | *d*0.6/0.4 m draw bench | 750 | 5 | 15~ 17 | 0.90~ 0.50 | |

brittle impurities in aviation apparatus axle journal alloy must be lower than 1.5. By using high-purity raw materials and other purifying processes, the purity of alloy was improved greatly. According to the criterion of 2BY322– 85, the impurities grade of cast alloy is 1.0~ 1.5, wire 0.5~ 1.0.

### 3.2 Hot forging and hot rolling

Cobalt-based alloys are hard to be deformed. High stress will be generated in the course of alternative heating and cooling, so the cogging of cast ingots should be carried out very carefully. Forging is suitable for cogging of cast ingots because its long interval is beneficial to recrystallization and recovery of ductility, and compressive stress generates during this procedure. In order to avoid the corner crack and structural inhomogeneity of forged ingots, heating speed, heating temperature and final forging temperature should be controlled strictly. During our process, the primary temperature of forging was 1 250 ℃, workpieces were heated two times and ultimately die-forged into rods 43 mm in diameter. The metallograph shown in Fig. 1(b) indicates that the crystal grain has been broken to be equiaxed, and the structure is more uniform than that of cast ingot(Fig. 1(a)).

In order to obtain fine grained alloy with uniform structure, the forging ingots were hot-rolled into slivers. Primary rolling temperature was 1 210 ℃, final rolling temperature was no lower than 900 ℃. Table 1 reveals that the cross-section shrinkage ratio of the first rolling was only 25%, and the crystals were fine and uniform (Fig. 1(c)), when the ingots were rolled to workpieces 25 mm in diameter. Therefore, deformation can be raised in the second hot rolling. The cross-section shrinkage ratio was 30%~ 35%, and the workpieces were rolled into slivers 8.5 mm in diameter. The total deformation ratio was 95%, and the internal structure was similar to the surface's. The structure of longitudinal section was fibrous(Fig. 1(d)).

### 3.3 Rotary forging

The hot-rolled slivers must be worked into fine rods 2.85 mm in diameter by many times of rotary forging before the wire-drawing is executed. The surface of rotary-forged rods must be smooth without any rags. Meanwhile, there is no longitudinal and cross micro fissure. So, the temperature of rotary forging and cross-section shrinkage ratio per time must be controlled strictly. If the temperature is too low, the distribution of strain and stress will not be uniform because of the inhomogeneity of deformation and structure of cross-section resulting from work-hardening, consequently, micro fissure will be formed at where the stress concentrates, leading to cleavage crack of rotary forging rods. On the other hand, too high temperature will lead to brittle recrystallization rupture. It is known from Table 2 that Co-W alloy rods are rotary-forged once and again, and the deformation ratio of each time is small. The metallograph of rotary-forged rod ($d$4.50 mm) shown in Fig. 1(e) indicates that ordered working structure does not yet form even when the total ratio of deformation was up to 76 percent, and local recrystallization has taken place. This phenomenon was caused by inhomogeneity of material deformation resulting from high deformation resistance of the alloy and low compression ratio of each procedure.

### 3.4 Wiredrawing

The long process of wire-drawing of Co-W alloy has many procedures, and the process parameters are difficult to be controlled and stabilized. For these reasons, wire rupture, wire diminishing and wire coiling often take place. Therefore, the choice and control of the temperature of furnace and die as well as the deformation ratio are of vital importance. If the temperature is too high, recrystallization will lead to wire rupture and wire diminishing. While the temperature is too low, the ratio of work-hardening will increase and concentrated internal stress will lead to the formation of micro fissure at the crystal boundary. The micro fissure will diffuse axially followed by the formation of macro-cracks leading to wire rupture. Small compression ratio of each procedure improve safety, however the deformation of wire is not homogeneous which is not beneficial to the formation of fiber structure, and wire coiling,

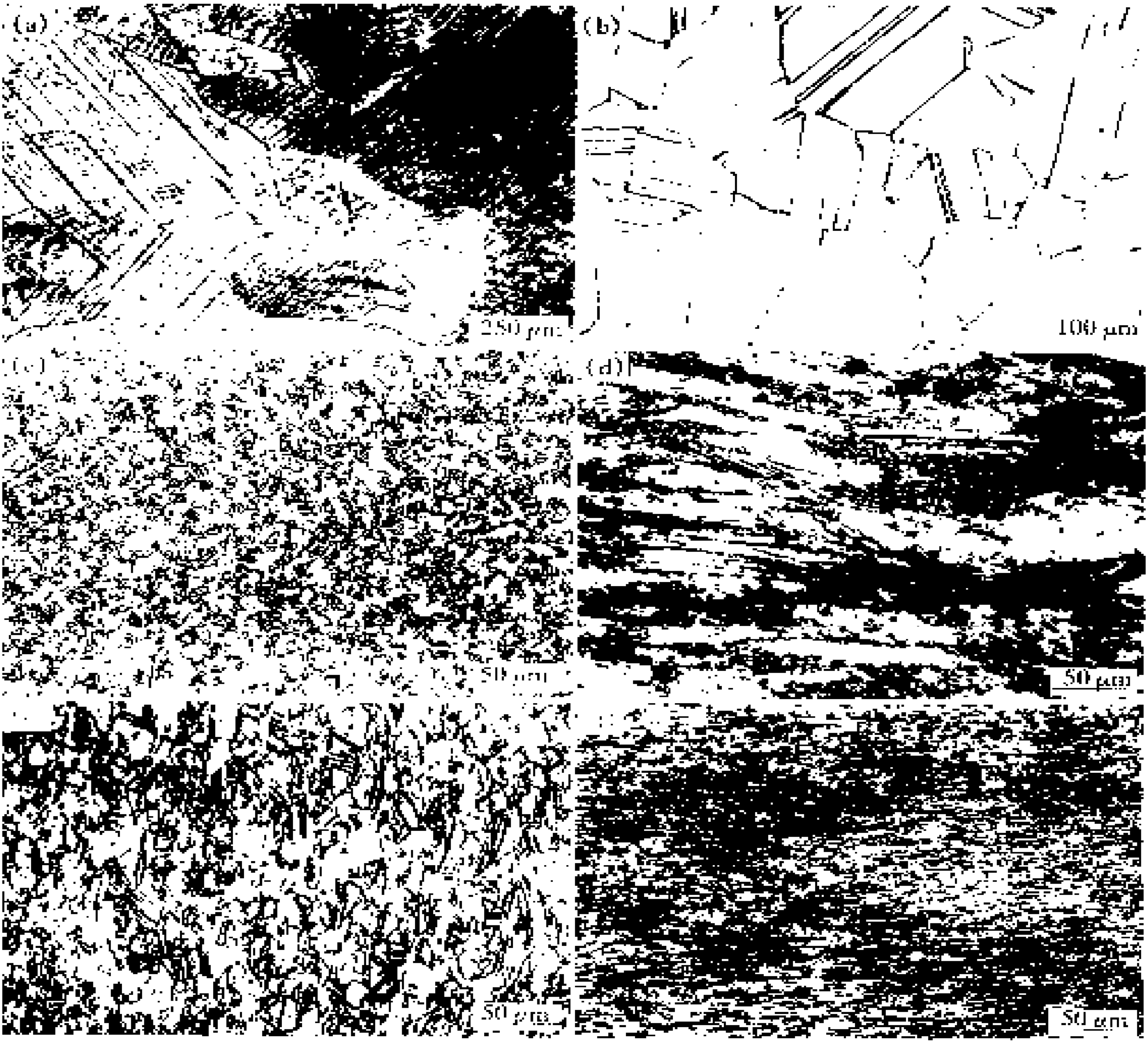


**Fig. 1 Metallographs of Co75W25 alloy**

(a) —Vacuum induction melted cast ingot; (b) —Hot-forged rod( $d$43 mm);
(c) —Longitudinal section of hot-rolled rods ( $d$25 mm); (d) —Longitudinal section of hot-rolled sliver( $d$8.5 mm);
(e) —Longitudinal section of rotary-forged rod( $d$4.5 mm); (f) —Longitudinal section of wires( $d$0.50 mm)

delamination and chromatic difference will generate easily[4]. According to these reasons, reasonable choice of compression ratio of each proceduce is very important. In the course of coarse, medium and fine wire-drawing, the reductions of wire diameter are controlled within 0.30~ 0.15 mm, 0.14~ 0.10 mm and 0.09~ 0.05 mm respectively, and 22~ 14 percent of cross-section shrinkage ratio is suitable. The metallographic structure of the wire ( $d$0.5 mm) shown in Fig. 1(f) represents the short fibre structure, which is different from tungsten wire's and molybdenum wire's, accordingly Co-W alloys are hard to be deformed.

### 3.5 Age-hardening of wires

Hardness of the wire with different diameter (shown in Table 3) was measured in order to study the change and uniformity of wires hardness in the course of wire-drawing. It is revealed by Table 3 that as-drawn wire's hardness can meet the requirements of application (4 500~5 500 MPa), and the hardness changed slightly with the increase of total deformation of wires because Co-W alloys were processed by means of hot working.

**Table 3 Hardness of wires in different diameters before aging**

| Diameter of wires/mm | 1.10 | 0.95 | 0.70 | 0.50 |
|---|---|---|---|---|
| Cross-section shrinkage ratio/% | 85 | 88 | 93 | 96 |
| Length of diagonal of impression/μm | 189 | 190 | 188 | 191 |
| Vickers hardness/MPa | 5 190 | 5 180 | 5 270 | 5 120 |

The wire must be corrected, cropped, grinding-cone and aged before processing into axle journal products. Axle journal can't be put into use until its hardness is more than 7 200 MPa after being aged. With the increase of aging temperature, the hardness of wires in different diameter increases too. The optimum temperature is between 600 ℃ and 650 ℃, and the Vickers hardness is up to 7200~ 8 000 MPa. If aging temperature is too high, the hardness will decrease rapidly.

Cobalt-based alloys are normally to be solid-solution strengthened, second-phase dispersion strengthened and crystal boundary strengthened[5, 6]. Tungsten is one of the basic strengthening elements of the alloys. $Co_3W$ and $Co_7W_6$, two intermediate phases, are formed between these two elements. The $Co_3W$ is strengthening phase, and $Co_7W_6$ brittle phase. It can be known from phase diagram of Co-W binary alloy system that the equilibrium condition of Co-25W alloy is the two-phased morphology of ε-Co and $Co_3W$. The morphology of as-drawn alloy is composed of α-Co solid solution and a small amount of ε-Co phase for the cooling speed of hot worked wire is rapid. The $Co_3W$ phase begins to precipitate when the aging temperature is higher than 550 ℃, so the hardness of the alloys is improved, and the effect of strengthening depends on the size and quantity of the precipitated phase[7, 8]. If the aging temperature is too low, and aging time too short, the quantity of $Co_3W$ phase is little, and the effect of strengthening is not obvious. On the other hand, as the aging temperature is too high (up to 750 ℃), $Co_3W$ phase will cluster and grow, leading to the decrease of hardness, which is called overaging (Fig. 3). It is obvious from Fig. 2 that the effect of age-hardening of the hot worked Co-W alloy wire is not sensitive to the amount of deformation. It is different from that of cold worked cobalt-based alloy with other composition (like Co40 alloy), which is strengthened by deformation heat treatment[9].

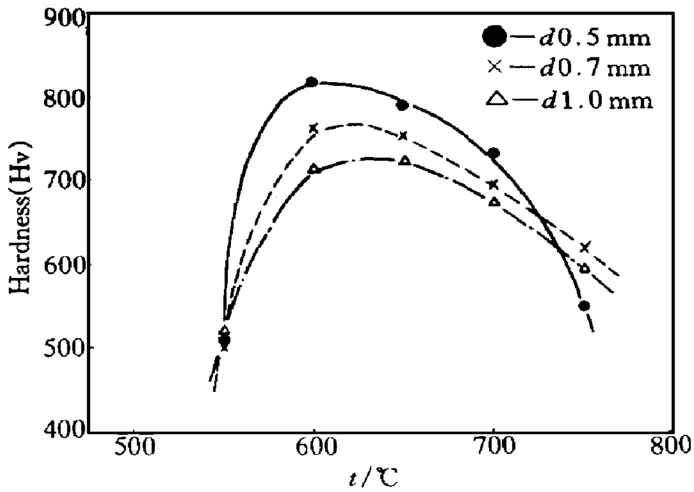


**Fig. 2 Relation between aging temperature and hardness**

## 4 CONCLUSIONS

(1) Co-25W alloy wire is an excellent material for the aviation apparatus axle journals.

(2) Co-25W alloy must be remelted in consumable-eletrode vacuum furnace after vacuum induction melting in order to reduce the content of harmful gas to improve the properties for wire-drawing.

(3) Process parameters of every procedure must be controlled strictly, and the choice of working temperature and deformation ratio is of vital importance because the processing properties of Co-25W alloy are poor.

(4) The strengthening mechanism of Co-25W alloys belongs to second phase precipitation

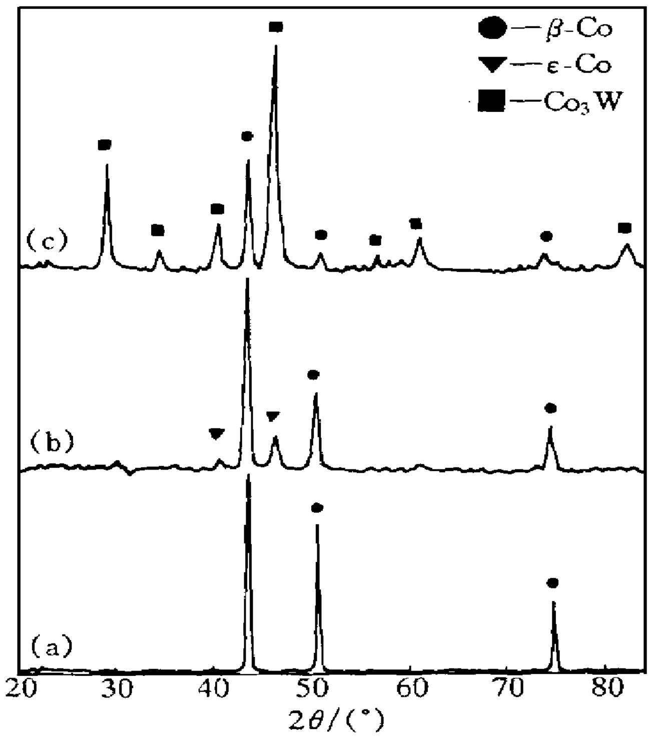


**Fig. 3 XRD patterns of Co-W alloy**

(a) —Consumable electrode remelted cast ingot;
(b) —As-rolled slivers of 8.50 mm in diameter;
(c) —Rolled slivers of 8.50 mm in diameter, aged at 650 ℃ for 8 h

strengthening. The optimum aging temperature is 650 ℃, and aging time 8 h. The ratio of deformation of hot working has no significant influence on the age strengthening.

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**(Edited by Yuan Saiqian)**