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Development of special lubricant for the zirconium alloy section cold rolling

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ABSTRACT

In order to improve the machining quality and reduce the energy consumption and the abrasion of roller and workpiece in the cold rolling process of zirconium alloy section, a special lubricant was developed. It uses 46# industrial white oil as base oil and the orthogonal decision method to select the appropriate additive formula. The results of physical and chemical properties analysis, rolling simulation test and practical application show that the developed oil can meet the requirements of zirconium alloy section cold rolling process.

1. Introduction

Zirconium, silver-white, is one of the highest melting point metal, light gray, whose density is 6.49 g/cm^3 and melting point 1852 ± 2 °C. Its surface is easy to form a layer of oxide film, with luster, so the appearance is similar to steel. Its corrosion resistance is better than titanium, close to niobium and tantalum, and soluble in aqua regia and hydrofluoric acid. At high temperatures, it can react with non-metallic elements. Elemental zirconium is of good plasticity, and easy to be processed into different sections (including plates, wire, etc.). When zirconium is processed, it can absorb a lot of hydrogen, oxygen, nitrogen and other gases, and can be used as hydrogen storage materials.

Zirconium is generally considered as a rare metal, in fact, the content of zirconium in the earth's crust is very rich, even more than the average non-ferrous metals such as copper, lead, nickel and tin. At present, the industrial-scale production of zirconium alloys are mainly two categories of zirconium-tin and zirconium-niobium alloy. They have excellent nuclear properties, heat absorption of small cross-section, and good corrosion resistance in the high temperature and water vapor; it can be made by plastic processing of different sections. Its welding performance is better to be welding. Therefore, zirconium alloys are widely used in aerospace, military, nuclear reactions, atomic energy, chemical engineering, marine engineering, medicine, biology and other related fields.

Rolling in the metal working process refers to a metal working method in which the shape and size of the metal section are changed between the rolls rotating the rolling mill, and the state and the performance of the metal are changed at the same time. Rolling is the process of continuous plastic deformation of metal, can produce different sections, and it has a high production efficiency. So it is the most widely used method of metal plastic processing. According to different degrees of metal work hardening, recovery and recrystallization in the process of rolling, it can be divided into hot rolling, cold rolling and warm rolling. Cold rolling refers to the rolling of the metal at the recrystallization temperature. Cold rolling is not recrystallization process, but can easily produce work hardening. In the cold rolling of zirconium alloy, the surface roughness is decreased with the increase of the rolling reduction and the rolling speed. Tiny wear powder produced in the rolling process will be attached to the surface of the roller or plate, which will make the surface roughness of the plate, reduce the surface quality of the section; it will bring difficulties to the subsequent heat treatment. In order to reduce the occurrence of such defects, it will be difficult to improve the process of rolling itself. Therefore, during the cold rolling of the zirconium alloy section, it is particularly important to select a good lubricant; it can reduce the degree of sticking zirconium in the rolling process and improve the surface quality of the rolled section.

In the cold rolling processing technology of zirconium alloy materials, the foreign countries have a monopoly of processing technology advantages. In the cold rolling process, China's existing

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lubricants have been unable to meet the cold-rolled zirconium alloy section process requirements, rely on imported lubricants, and the price is expensive [1]. With the rapid development of China's nuclear power, industries require a large number of cold-rolled zirconium alloy sections. In view of this, it is very necessary to develop a special lubricant for zirconium alloy sections cold rolling with independent intellectual property rights. In this study, based on many years of practical engineering experience and the application of relevant mathematical methods from the four groups of base oil, we selected the appropriate base oil, and screened the corresponding functional additive formulations; a special lubricant suitable for commercialization of zirconium alloy sections was developed.

2. Selection of base oil

In the cold rolling process of zirconium alloy materials, not only lubricants are required to have good lubrication, cooling, cleaning, shear stability and thermal oxidation stability, also need to have a high metal surface adsorption capacity, diffusion and permeability. This will ensure that a lubricating oil film with a certain thickness and strength can be quickly formed between the roller and workpiece, to reduce the friction coefficient, rolling and roller adhesion, coking, energy consumption and abrasion of the roller and workpiece.

As the zirconium alloy material has significant anisotropy. In the cold rolling process, the high rebound strength, tensile strength and yield strength will increase with the increase in processing rate; elongation with the increase in processing rate decreases. Cold rolling can cause significant work-hardening of the material. Therefore, cold rolling must be preceded by an annealing treatment in order to easily obtain the required mechanical properties of materials. In the development process to select the base oil, the first consideration is the good annealing cleaning and anti-coking properties. Generally, the higher the saturated hydrocarbon content of the base oil, the better the annealing performance is it. The lower the sulfur content and the aromatics, the less the surface contamination after annealing is it.

To select the appropriate base oil, the typical physical and chemical indicators of four groups of base oil was tested, as shown in Table 1.

It can be seen from Table 1 that the kinematic viscosity of hydrogenation base oil is too low, which cannot meet the zirconium alloy cold rolling process lubrication requirements. The kinematic viscosity of castor oil is suitable, but the annealing performance is poor. The 10# industrial white oil, due to the low kinematic viscosity, its flash point and unfavorable to safety, has been ruled out. The 46# industrial white oil, because of its appropriate kinematic viscosity, good annealing performance, relatively low sulfur content and aromatics content, and better additive compatibility, has been used as the base oil.

3. Selection of additives

3.1. Selection of oiliness additive

As a result of the lubricating characteristic request, certain amount of oiliness additive should be added in the base oil. It can form a directional adsorption film on the friction surface, then reduce the possibility of direct contact with metal and the friction coefficient and abrasion. At the same time, it can enhance the oil film strength and make up the deficiency of basic oil lubrication performance. Animal and vegetable oils, oleic acid, stearic acid, and fatty alcohols are usually used as the oiliness additive. In previous studies, butyl stearate was found to have the better annealing cleanliness, so that the sections could easy to obtain better surface quality and the alkyl phosphtie ester was found to have the ability to improve the strength of the oil film [2].

In the experiment, we used butyl stearate and alkyl phosphite ester compound as the oiliness additive, and the optimal proportion of the two was determined by the approximation experiment. In the experiment, the mass mixing ratio of butyl stearate and alkyl phosphite ester was 40:60 (A1), 50:50 (A2), and 60:40 (A3). The compound oiliness additive was mixed with base oil in the ratio of 2: (B1), 4% (B2), 6% (B3), and 8% (B4). The oil film strength and the annealing and cleaning performance were determined by using the lubricant bearing capacity test method (four-ball method) GB/T3142, as shown it Table 2.

Table 1
Typical physical and chemical indexes.

Object	40 °C kinematic viscosity/mm s^{-1}	Open flash point/°C	Pour point/°C	Sulfur content/(μg/mL)	Aromatic hydrocarbons/%	Annealing cleanliness/grade	Distillation range/°C
Standard	≥30	≥160	≤-10	≤100	≤10	≤3	280–370
Vacuum gas oil hydro-treating	6.72	184	−22	11	7.02	≥2	340–405
Castor oil	230.65	242	<-10	0	0	≥5	–
10# industrial white oil	8.81	162	−5	≤20	5.36	≥2	360–420
46# industrial white oil	45.33	198	−15	≤10	3.58	1	370–430

Table 2
The effect of the amount of compound oiliness additive on the performance of oil film strength and annealing cleanliness.

Sample	Butyl stearate: alkyl phosphite ester	Compound oiliness additive: base oil/%	Oil film strength (PB/N)	Annealing cleanliness/Level
1 (A1+B1)	40:60	2	281	IV
2 (A1+B2)	40:60	4	326	III
3 (A1+B3)	40:60	6	366	II
4 (A1+B4)	40:60	8	409	I
5 (A2+B1)	50:50	2	272	IV
6 (A2+B2)	50:50	4	314	II
7 (A2+B3)	50:50	6	341	I
8 (A2+B4)	50:50	8	398	I
9 (A3+B1)	60:40	2	245	IV
10 (A3+B2)	60:40	4	295	II
11 (A3+B3)	60:40	6	337	I
12 (A3+B4)	60:40	8	358	I